§ 2 Automation Device Systems and Structures

2.1 Automation Computers

2.2 Centralized and Decentralized Structures

2.3 Automation Hierarchies

2.4 Distributed Automation Systems

2.5 Automation Structures with Redundancy

Chapter 2 - Learning targets

- to know the different automation computers
- to know what is the special of the mode of operation of a PLC
- to be able to differ between centralized and decentralized structures
- to recognize combinations of automation system structures
- to know automation hierarchies and their requirements
- to understand what distributed automation systems are
- to know what the basic topologies of communication are
- to be able to differ between an open and a proprietary communication system
- to know what is meant by redundancy
- to know kinds of hardware redundancy and to be able to characterize them
- to be able to explain what is meant by diversity

§ 2 Automation Device Systems and Structures

2.1 Automation computers

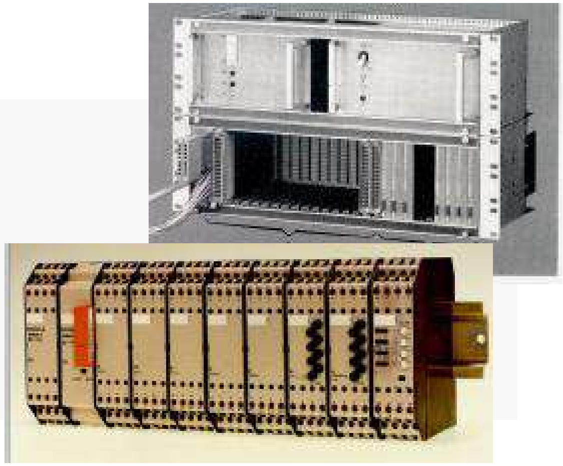
2.2 Centralized and decentralized structures

2.3 Automation hierarchies

2.4 Distributed automation systems

2.5 Automation structures with redundancy

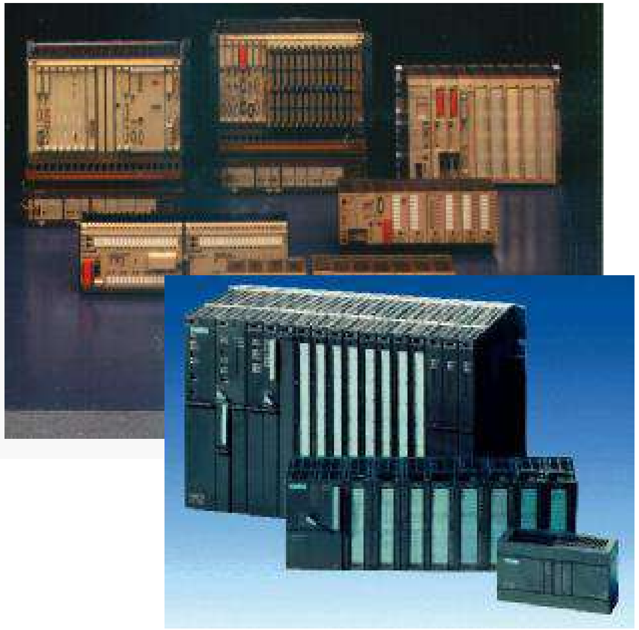
Situation (1)



- Programmable Logic Controllers since 1972
- Influenced by components and technologies
- Dependent on the task
- Beginning of the software

è Increase of the functionality and efficiency of the programmable logic controllers

1980	:	2	kByte
1990	:	20	kByte
2000	:	2000	kByte



Situation (2)

– Target groups
  - user without computer science studies
  - "electrician"

– Target for the use of PLCs
  - replace contactor/relay
  - increase reliability
  - reduce costs

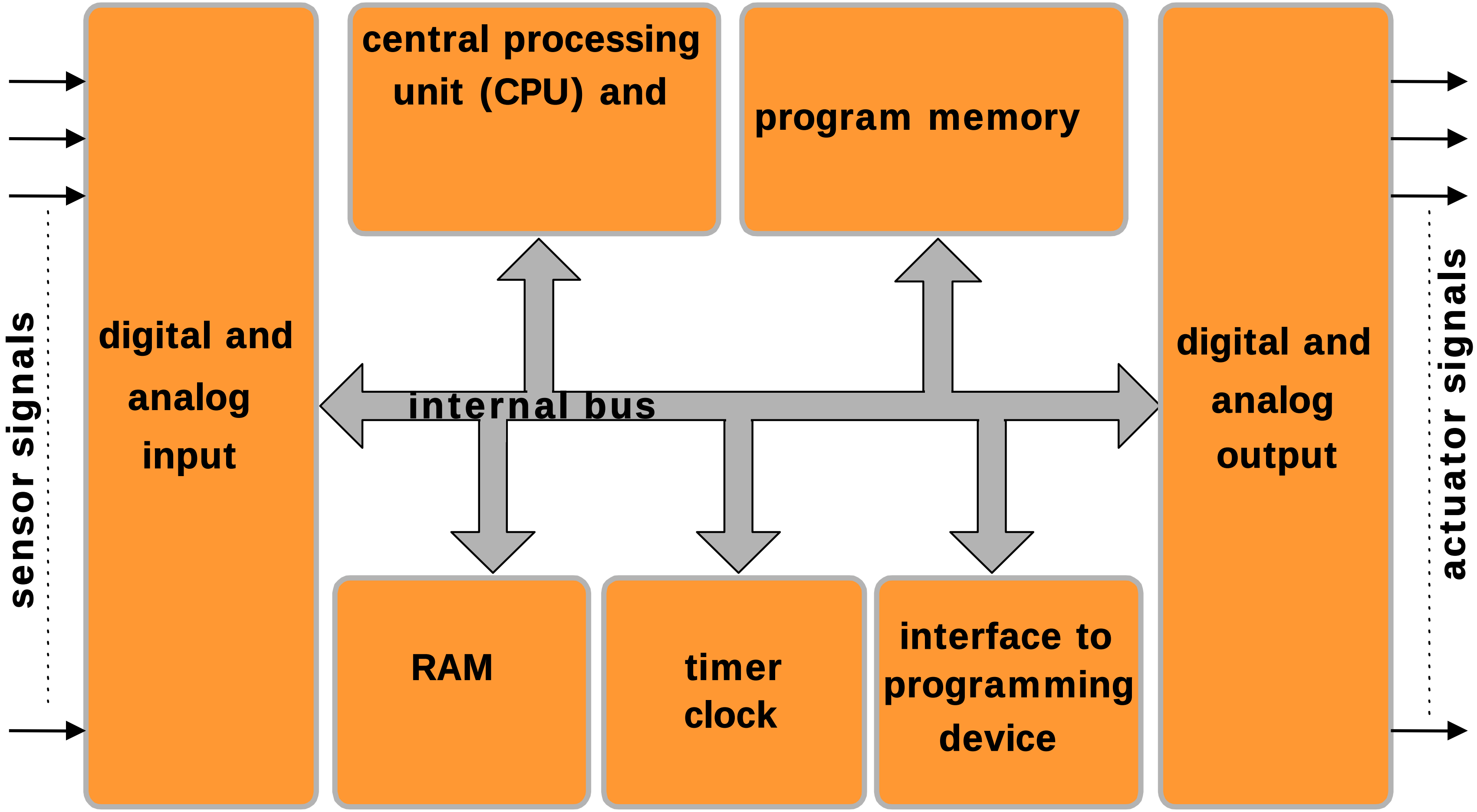
– Target for the PLC languages
  - to describe functions in known representations
    - ú ladder diagram (derived from the circuit diagram)
    - ú function plan (derived from the logic plan)

è Standardization of the development of PLC systems

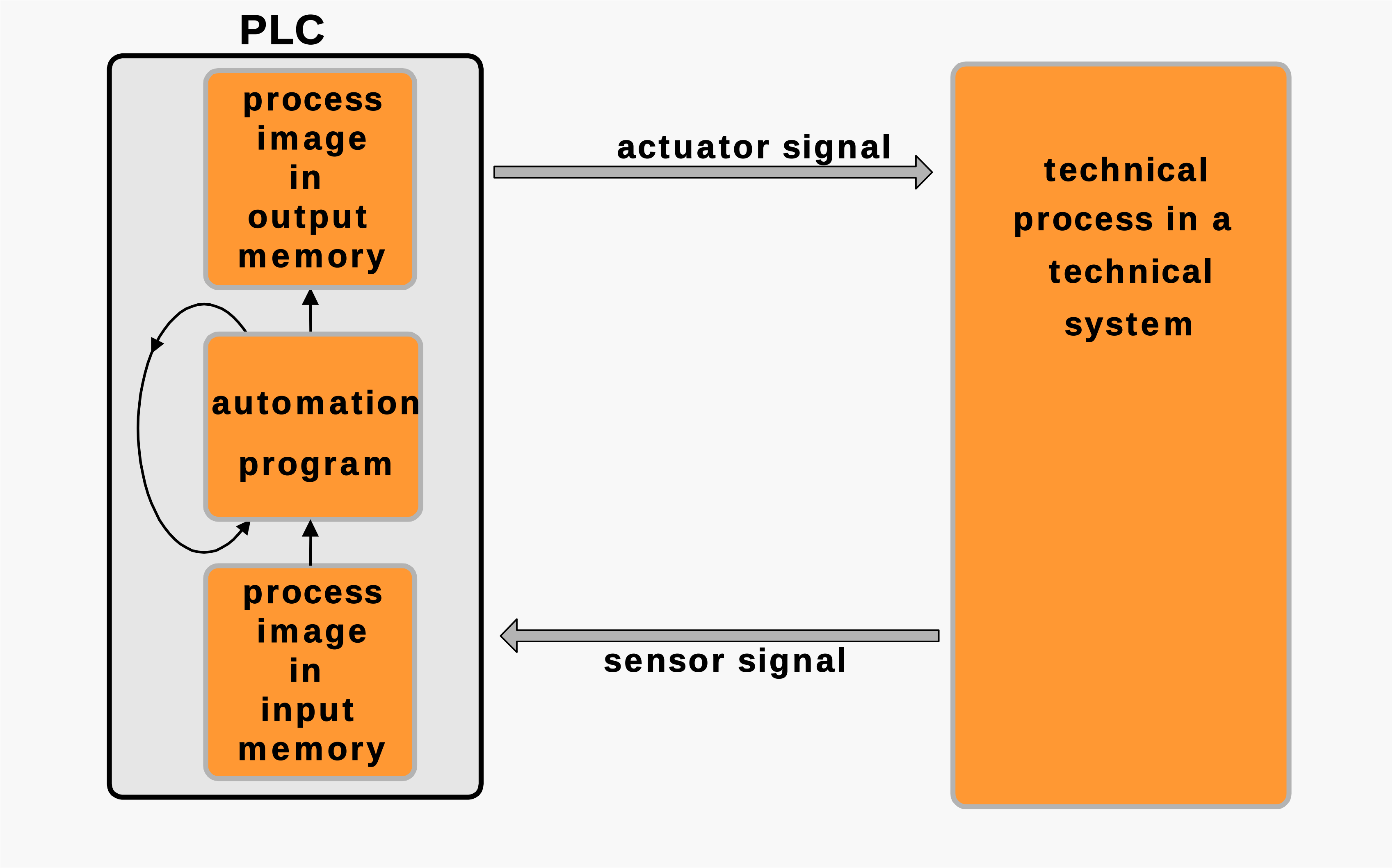
IEC 1131

DIN EN 611131

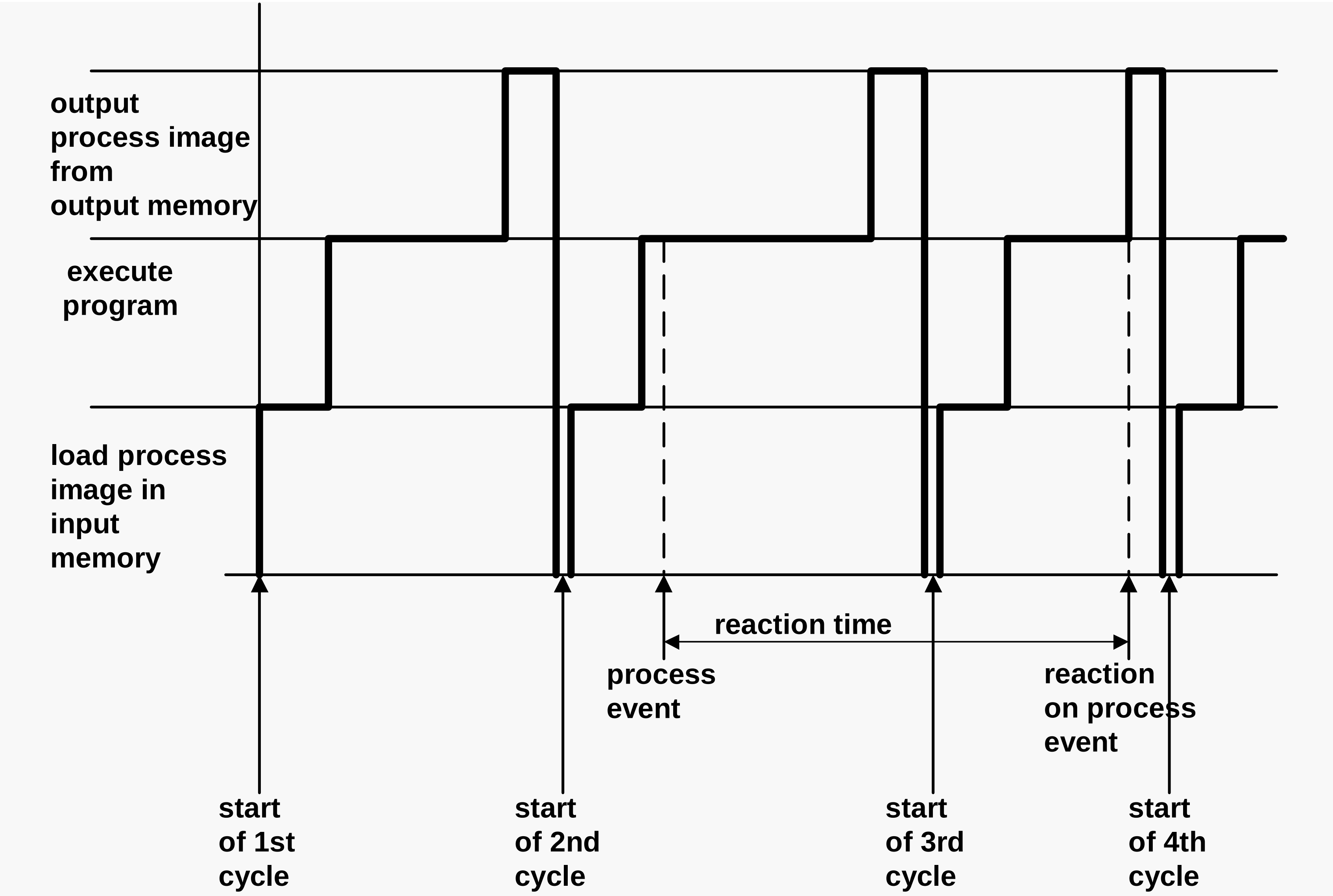
Block diagram of the hardware structure of a PLC



Cyclic operation of a PLC


PLC
process image in output memory
automation program
process image in input memory
actuator signal
sensor signal
technical process in a technical system

Sequence of a cyclic program execution for a PLC



Features of PLC

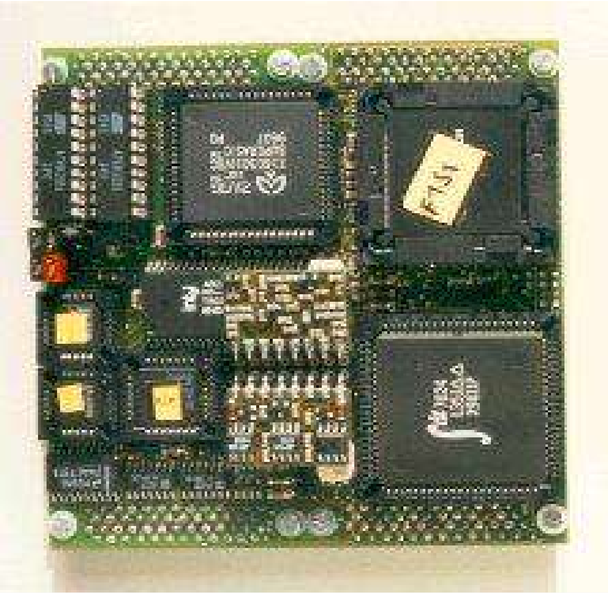
Advantage: simple programming through cyclic operational mode

Disadvantage: maximum reaction time on events in the technical process is equal to two program cycles

Program execution time:

- **cycle time is not constant**
- **1 ms per 1000 instructions**

Microcontroller (One-chip-computer)



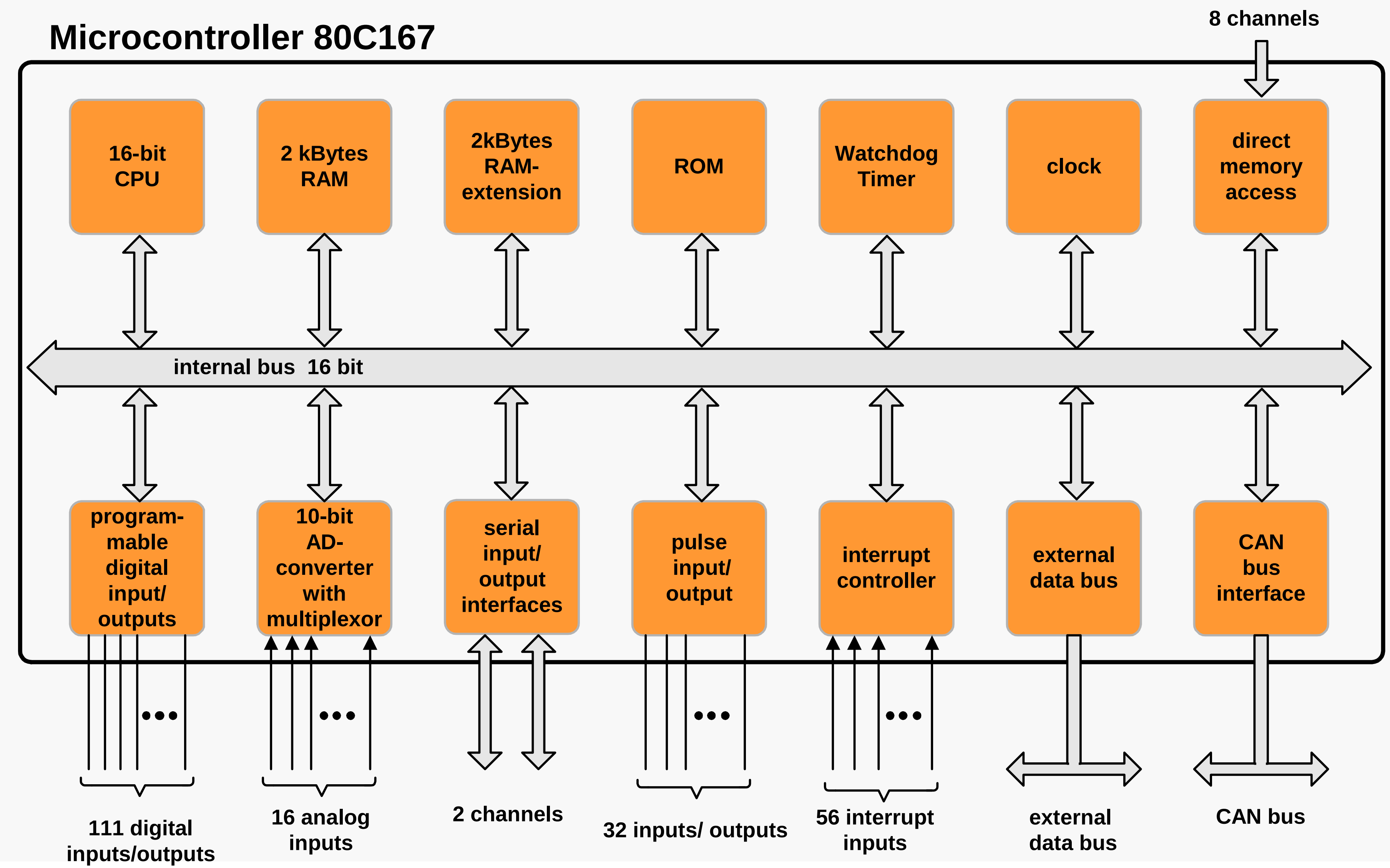
- highly integrated components
- employment for mass products
- composition of
  - standard micro processor
  - data memory / program memory
  - bus interfaces
  - process signal interfaces
- programming with development system
- short word length
- extremely low price

beginning at: 1- 10 €

- good reliability and long life span
- high requirements regarding environmental conditions

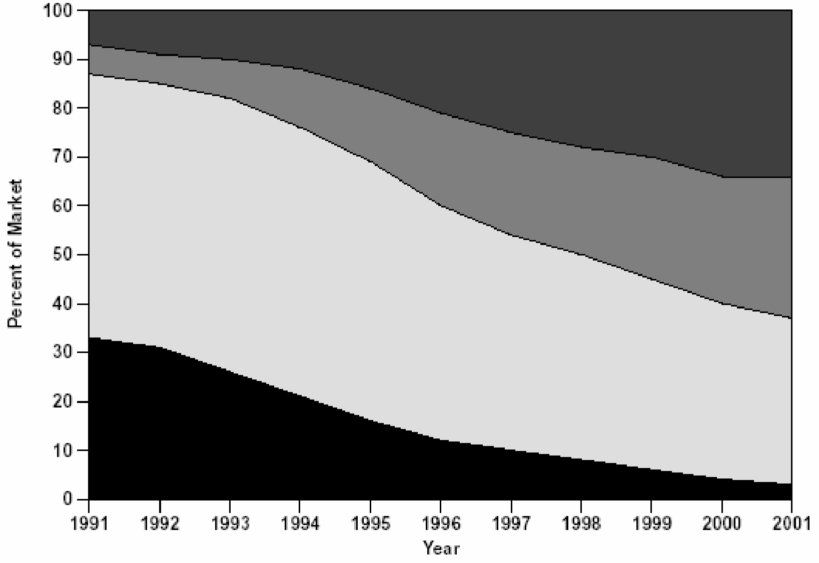
temperature, humidity

Simplified block diagram of a micro controller



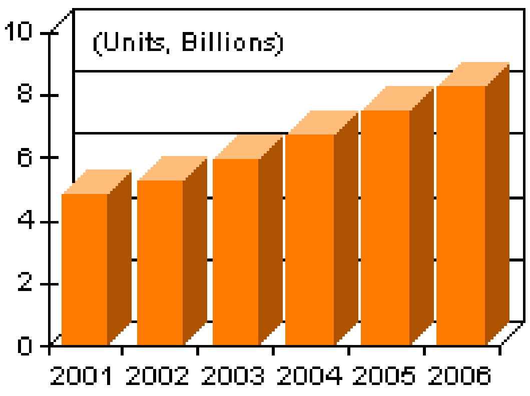
World market for microcontrollers

- Manufacturers:
  Intel, Motorola, National Semiconductor, Toshiba, Infineon, Mitsubishi
- World-wide increasing market
- Increasing tendency to 16-/32bit microcontroller and specific digital signal processors



■	4-bit	33%	31%	26%	21%	16%	12%	10%	8%	6%	4%	3%
□	8-bit	54%	54%	56%	55%	53%	48%	44%	42%	39%	36%	34%
▒	16-/32-bit	6%	6%	8%	12%	15%	19%	21%	22%	25%	26%	29%
▓	DSP	7%	9%	10%	12%	16%	21%	25%	28%	30%	34%	34%

Worldwide Microcontroller Shipments Forecast



Source: In-Stat/MDR 8/02

Differentiation

- Microprocessor

  processor on a micro electronic chip

- Microcomputer

  all components on a micro electronic chip i.e., processor, memory, interface to periphery

- Microcontroller

  automation computer or an automation computer system on one chip

Basic terms

CPU = Central Processing Unit

micro processor

RAM = Random Access Memory

data memory

EPROM/PROM/ROM = Erasable/ Programmable/ Read Only Memory

fixed memory

I/O = parallel or serial input/output components

process and data periphery

Counter/Timer = generation of clock pulses

Interrupt Controller = handling of hardware interrupts

Industrial PC (IPC)

- Pluggable circuit boards for connection of
  - electrical process signals
  - optical process signals
  - bus systems
- Programming in high-level language
- Use of real-time operating systems
  - as single operating system
  - in addition to standard operating systems

Operational areas of industrial PCs

- Process visualization
- Process evaluation and monitoring
- Superordinated control tasks (control room tasks)

Environmental conditions

- Harsh environmental conditions
  - temperature variations
  - shocks and vibrations
  - dust and humidity
  - electrical or electromagnetic disturbances

- Protective measures in industrial PCs (IPC)
  - vibration absorbing disk drives
  - high quality of integrated components
  - special protecting case

Protection forms of industrial PCs with IP index

1st digit	Protection against solid objects	2nd digit	Protection against water impact
0	No protection	0	No protection
1	Hand contact impossible (50mm objects)	1	Protection against vertical falling drops/ condensation
2	Finger contact impossible (12mm objects)	2	Protection against drops with a falling angle of 15°
3	Wire contact impossible (2.5mm objects)	3	Protection against rain fall up to 60°
4	Fine wire contact impossible (1.0mm objects)	4	Protection against spray from all directions
5	Protection against harmful dust	5	Protection against jets of water from all directions
6	Complete dust protection	6	Protection against water floods (during heavy sea)
		7	Protection against water impact up to a depth of 1m
		8	Protection against persistent water impact for depths larger than 1m

IP =
Ingress Protection

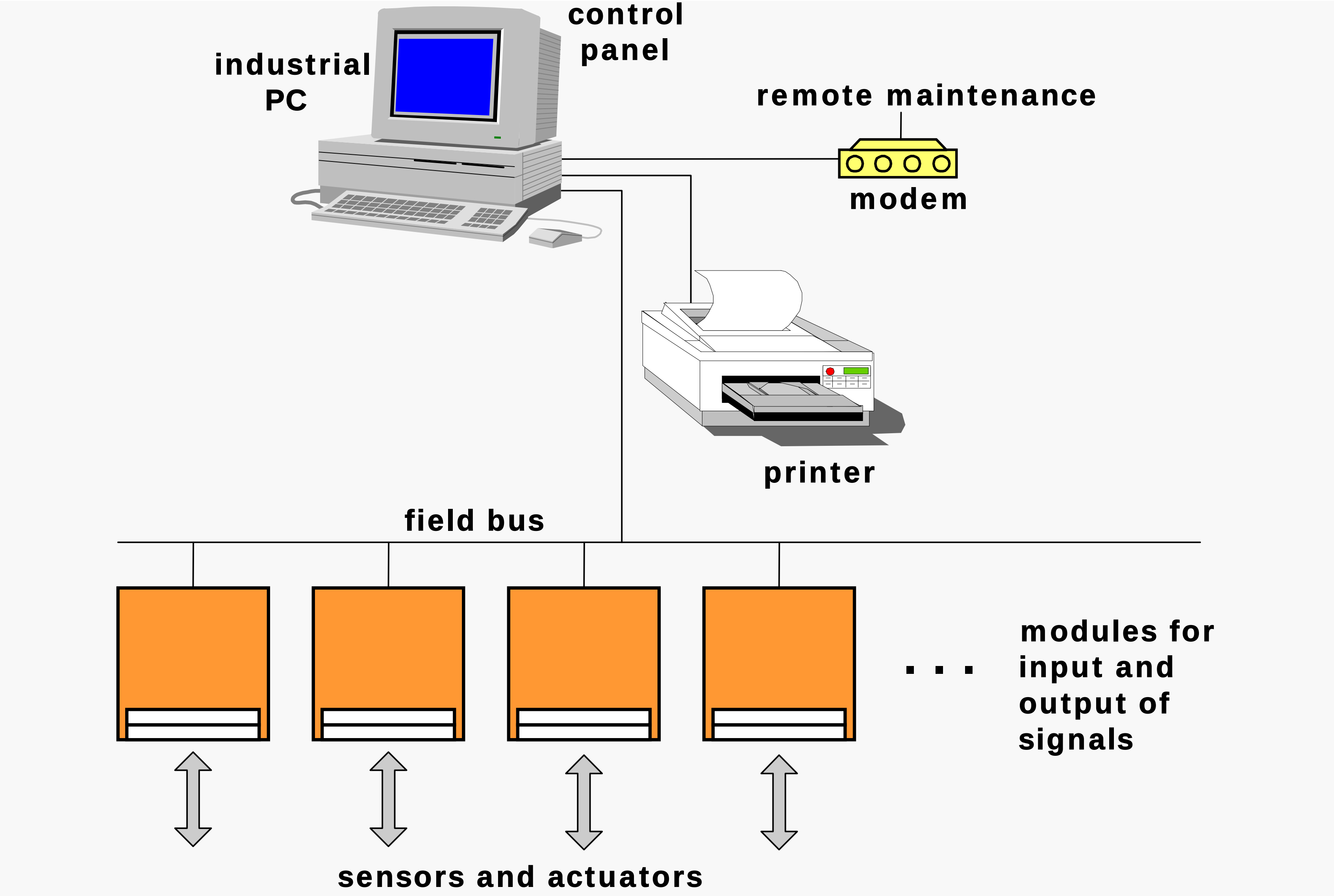
Pure IPC solution

- acquisition of process data
- execution of control program under real-time conditions
- interface to the user

Advantages of a pure IPC-solution

- better scalability of hardware
- many operating systems available
- wide spectrum of programming languages available
- open system for the integration of ready-made subsystems

Structure of a pure IPC system



Structure of a PLC-IPC system (chalkboard writing)

Process control system (PCS)

- Distributed computer systems, connected via bus systems
- Interconnection with PLC computers
- Usage of prefabricated program modules developed by the Manufacturer of the PCS
- Configuration by operator

Complete solutions from a single manufacturer

- No compatibility problems
- Uniform process operation and monitoring
- High availability
- Defined responsibility
- Long lifetime

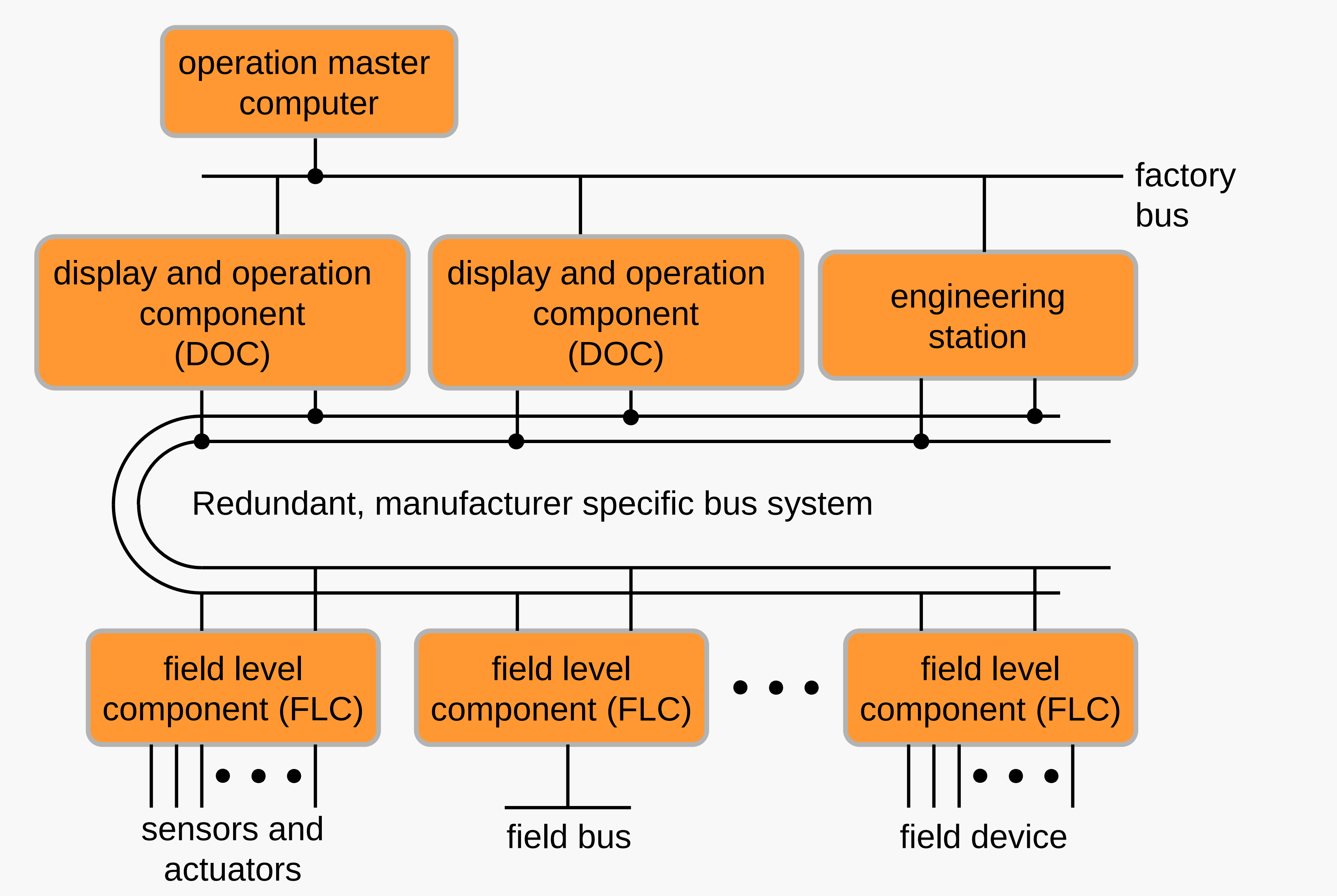
Fields of application of process control systems

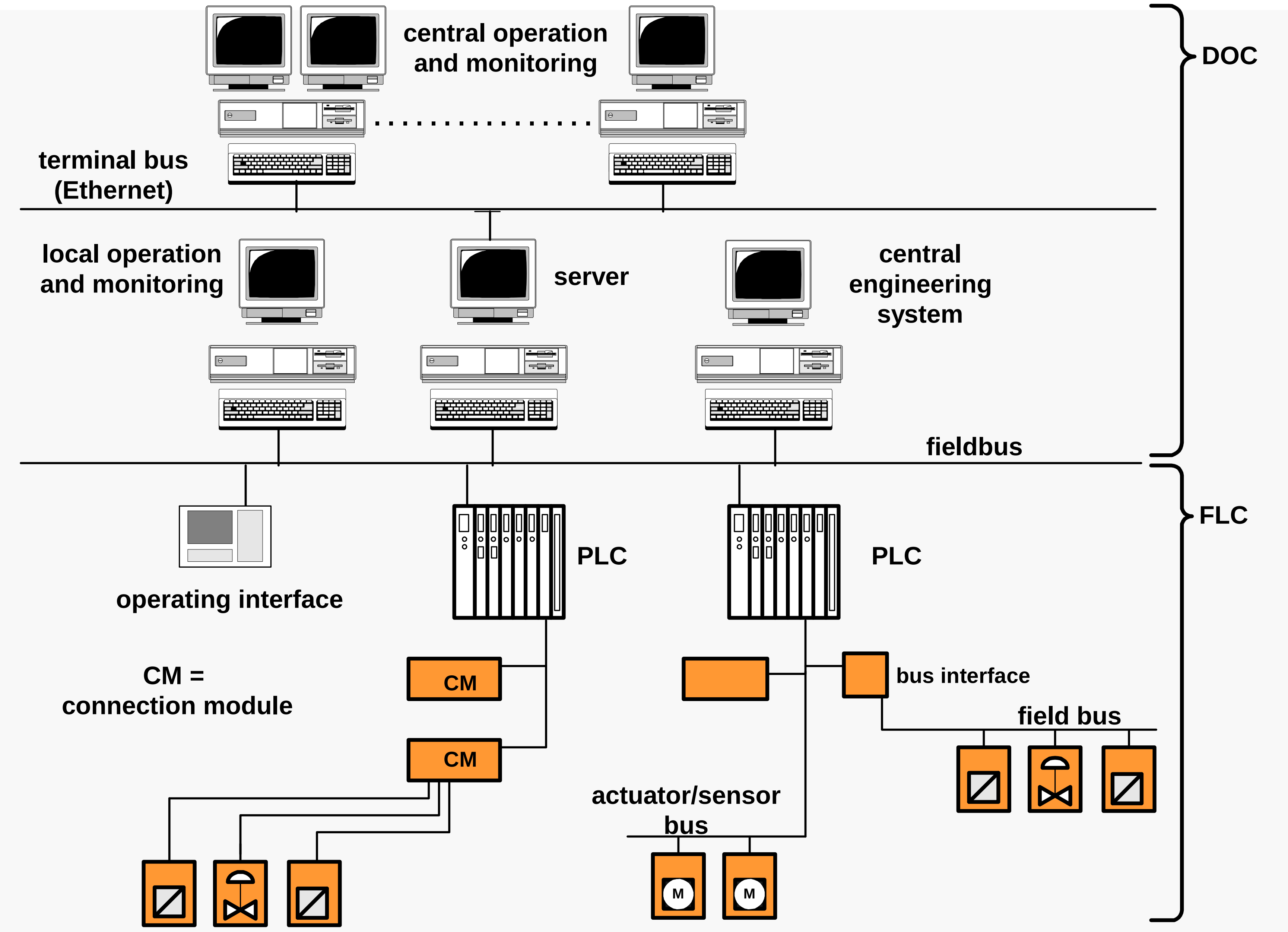
- Power plant automation
- Process engineering
- Building automation
- Production engineering

Components of a PCS

- Operation and monitoring components
- Field level components
- Communication systems
- Engineering tool

Schematic structure


operation master computer
factory bus
display and operation component (DOC)
display and operation component (DOC)
engineering station
Redundant, manufacturer specific bus system
field level component (FLC)
field level component (FLC)
field level component (FLC)
sensors and actuators
field bus
field device


central operation
and monitoring
DOC
terminal bus
(Ethernet)
local operation
and monitoring
server
central
engineering
system
fieldbus
FLC
operating interface
PLC
PLC
CM =
connection module
CM
CM
bus interface
field bus
actuator/sensor
bus
M
M

Operation and monitoring components

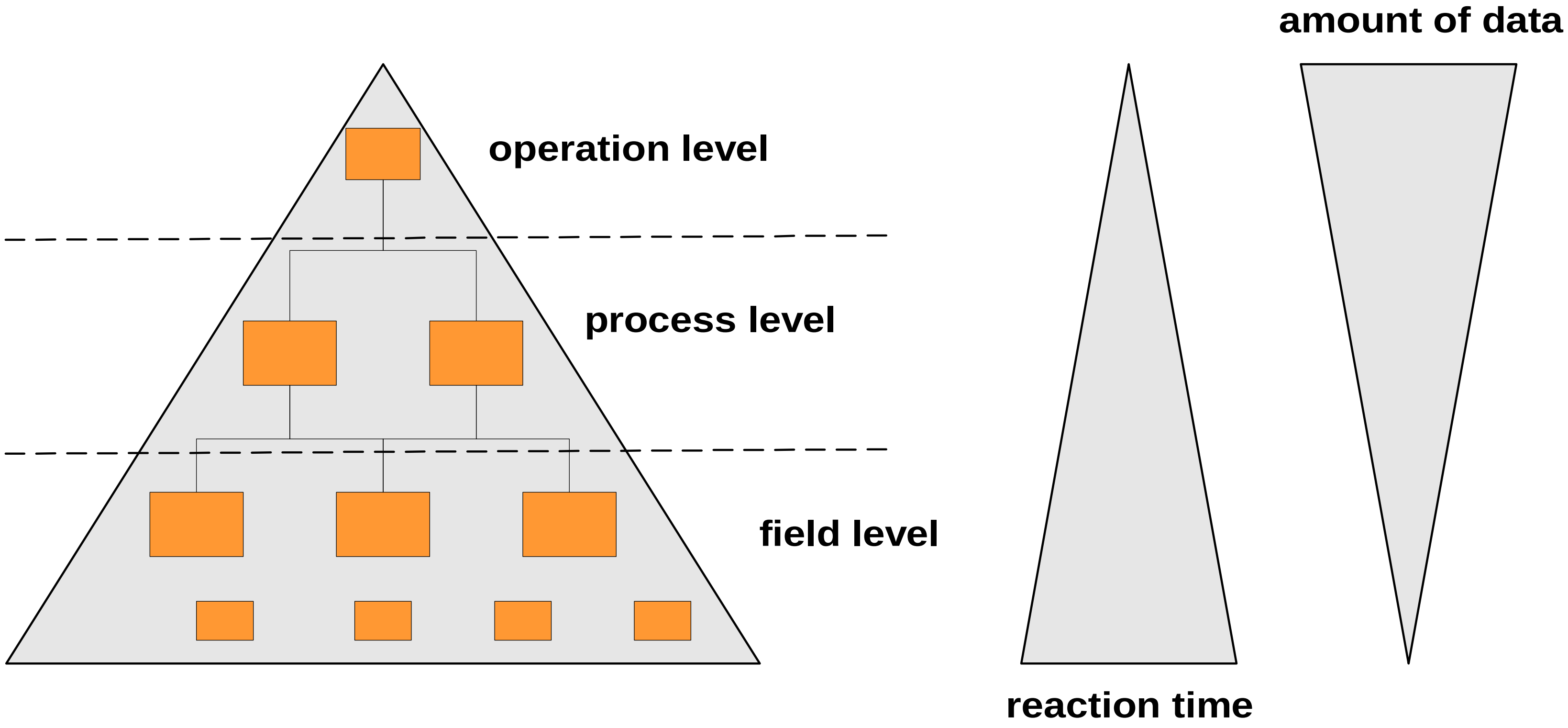
- Functions:
  - create/modify recipes/batch processes
  - change current values
  - communication with the process
  - process alarm messages and operating requirements
  - process visualization
  - interface to data base system for process data logging
- Realization:
  - PC, IPC, Workstation
  - Windows 95, Windows NT, Unix

Components at the field level

- In-house developments of the control system - manufacturer (proprietary solution)

- Setup
  - automation computer : PLC, IPC
  - distributed periphery
  - field devices: sensors, actuators

System communication



Bus systems	
Operation level:	standardized Ethernet bus
Process and field level:	Field bus, e.g. Profibus, H1-Bus, Modbus, Interbus-S
Lowest field level :	fast actuator-sensor buses

Engineering

- Tasks
  - Configuration
  - Programming
  - Maintenance

- Tools
  - Graphical tools (IEC 1131)
  - Standardized libraries with components
  - Powerful editors

Control system manufacturers and their products

Manufacturer	Name of the product	Remarks
ABB	AdvantOCS	Company-specific field bus
	AdvaSoft	For small systems
	Procontrol P	Power plant automation
EB Hartmann & Braun	Symphony	Supports connection to operation level, remote I/O System automation for large systems
	Contronic E	Power plant automation, for large installations
	Contronic P	Process engineering, extension up to 12km
Foxboro-Eckardt	I/A Serie-System	Process engineering, field level with PCMCIA-technology
Siemens	SIMATIC PCS 7	Process engineering, user interface based on Windows 95 and Windows NT. Extensive hardware supply. Field bus: Profibus. Connection to operation level possible.
	Teleperm M	Process engineering, common old bus system (CS 275). Migration from Teleperm M to SIMATIC PCS 7 possible.
	Teleperm XP	Power plant automation, open communication, extensive hardware supply.
Honeywell	PlantScape	Process engineering, open system, based on Windows NT, supports remote I/O. Connection to operation level possible.
	TDC 3000	Process engineering, has several process buses with different data transmission. MODBUS is supported.

§ 2 Automation Device Systems and Structures

2.1	Automation computers
2.2	**Automation structures**
2.3	Automation hierarchies
2.4	Distributed automation systems
2.5	Automation structures with redundancy

Structure of the technical process

- technical process as an entity
  e.g.: drilling process with a drilling machine
- technical process consisting of sub-processes
  e.g.: manufacturing of a gear

Structure of automation devices

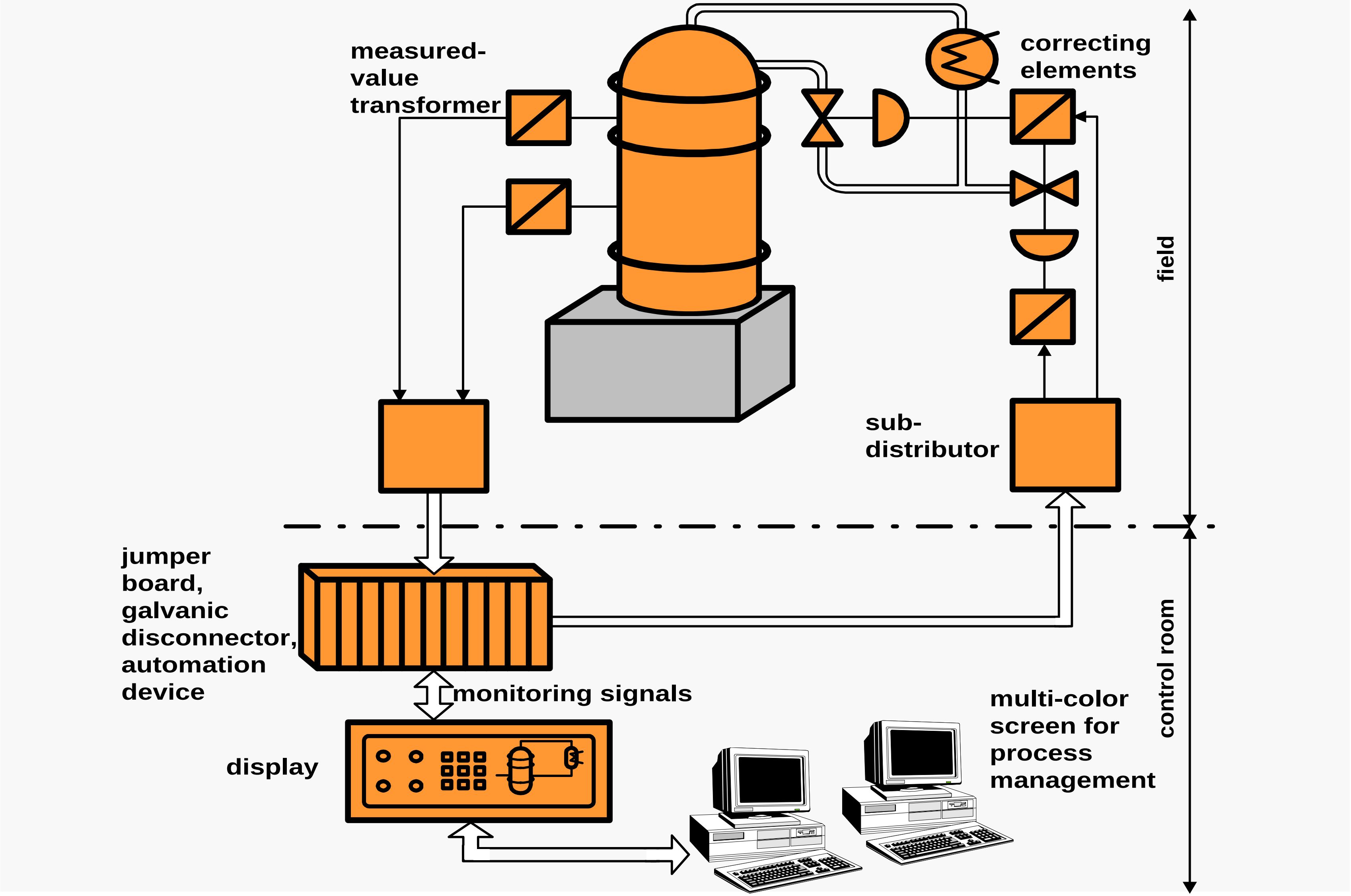
- locally concentrated
- locally distributed

Functional structure of automation systems

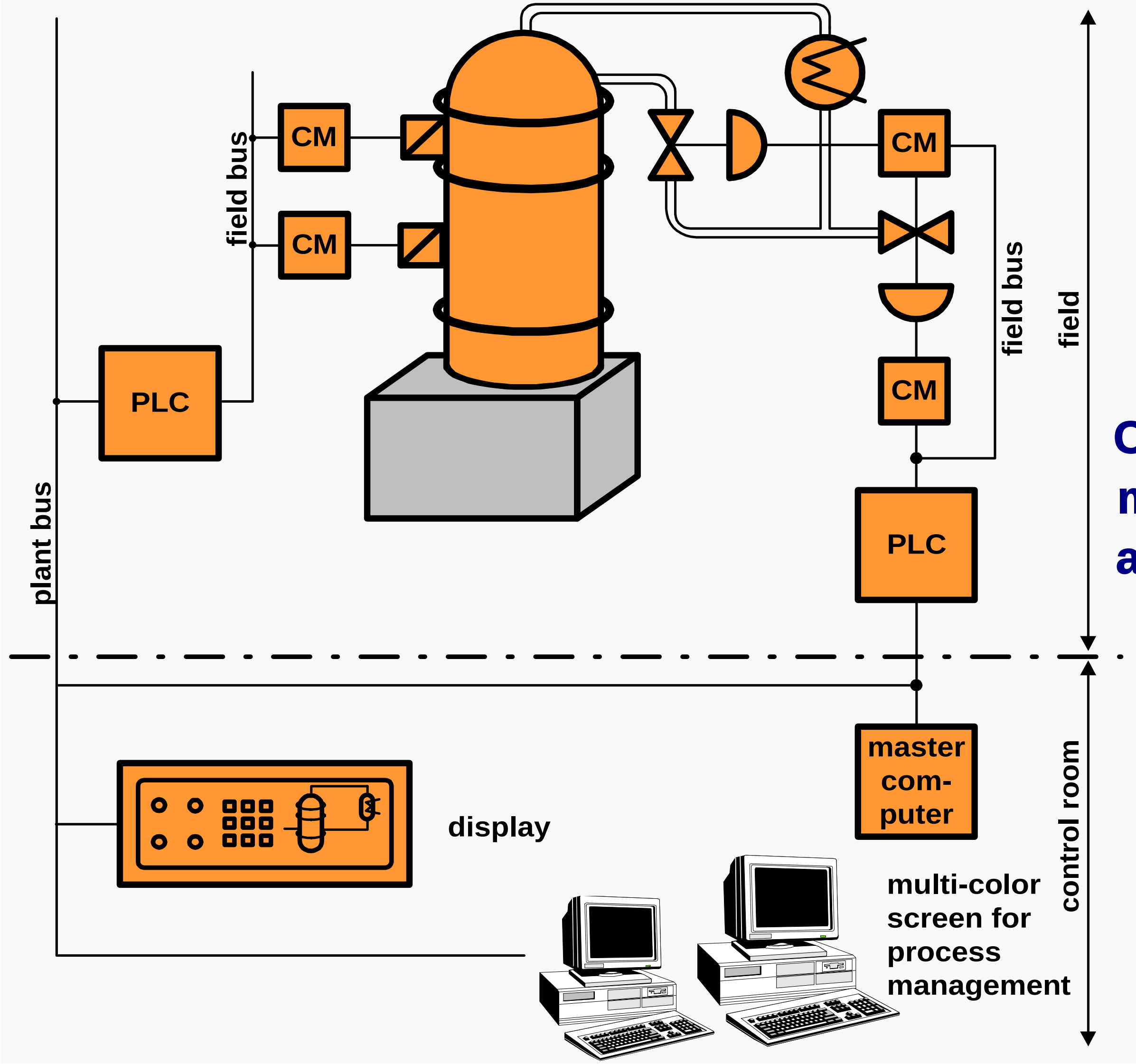
= allocation of automation functions on the automation devices

- functionally centralized
- functionally decentralized

Locally concentrated automation devices

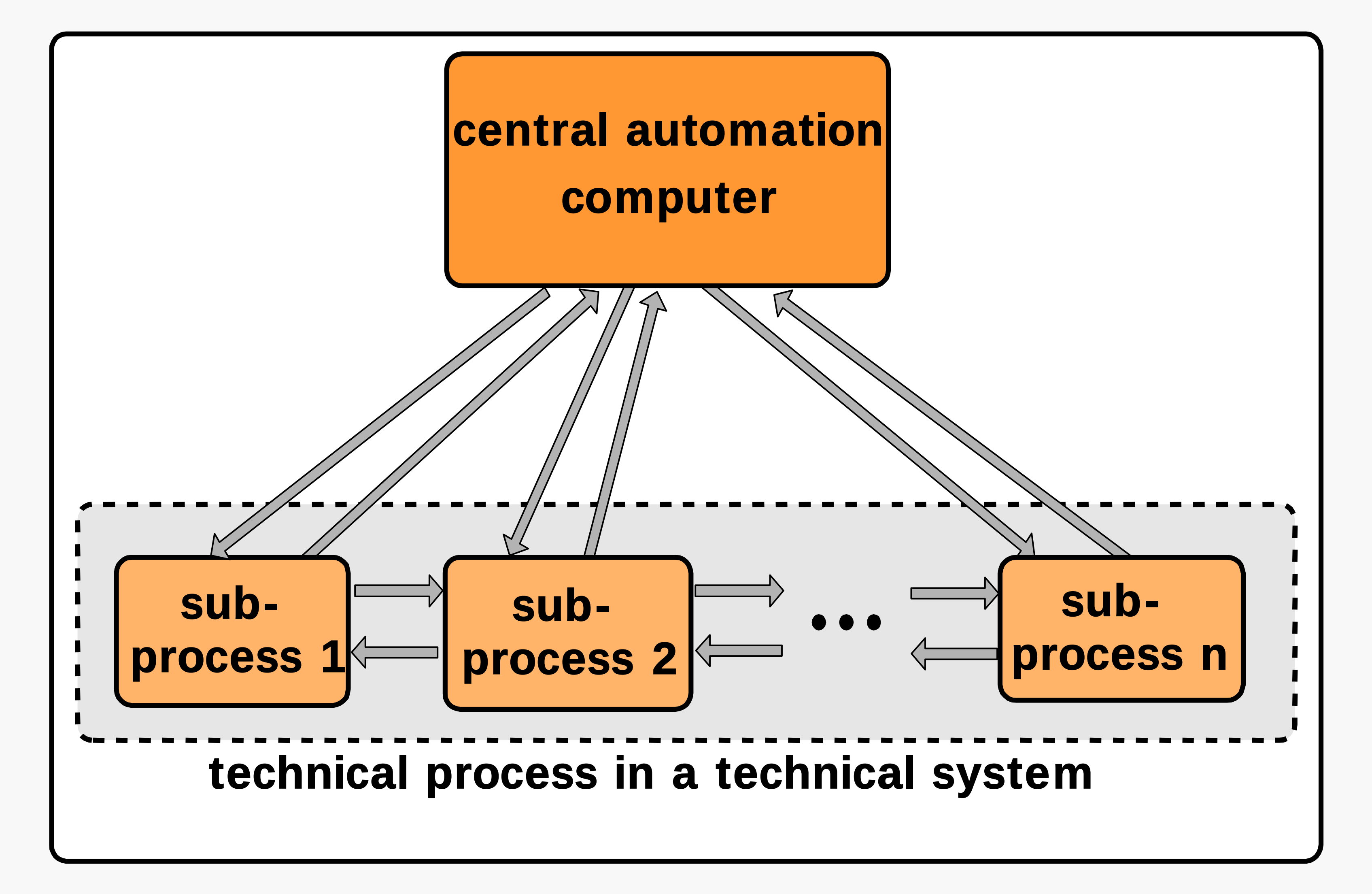


Locally distributed automation devices

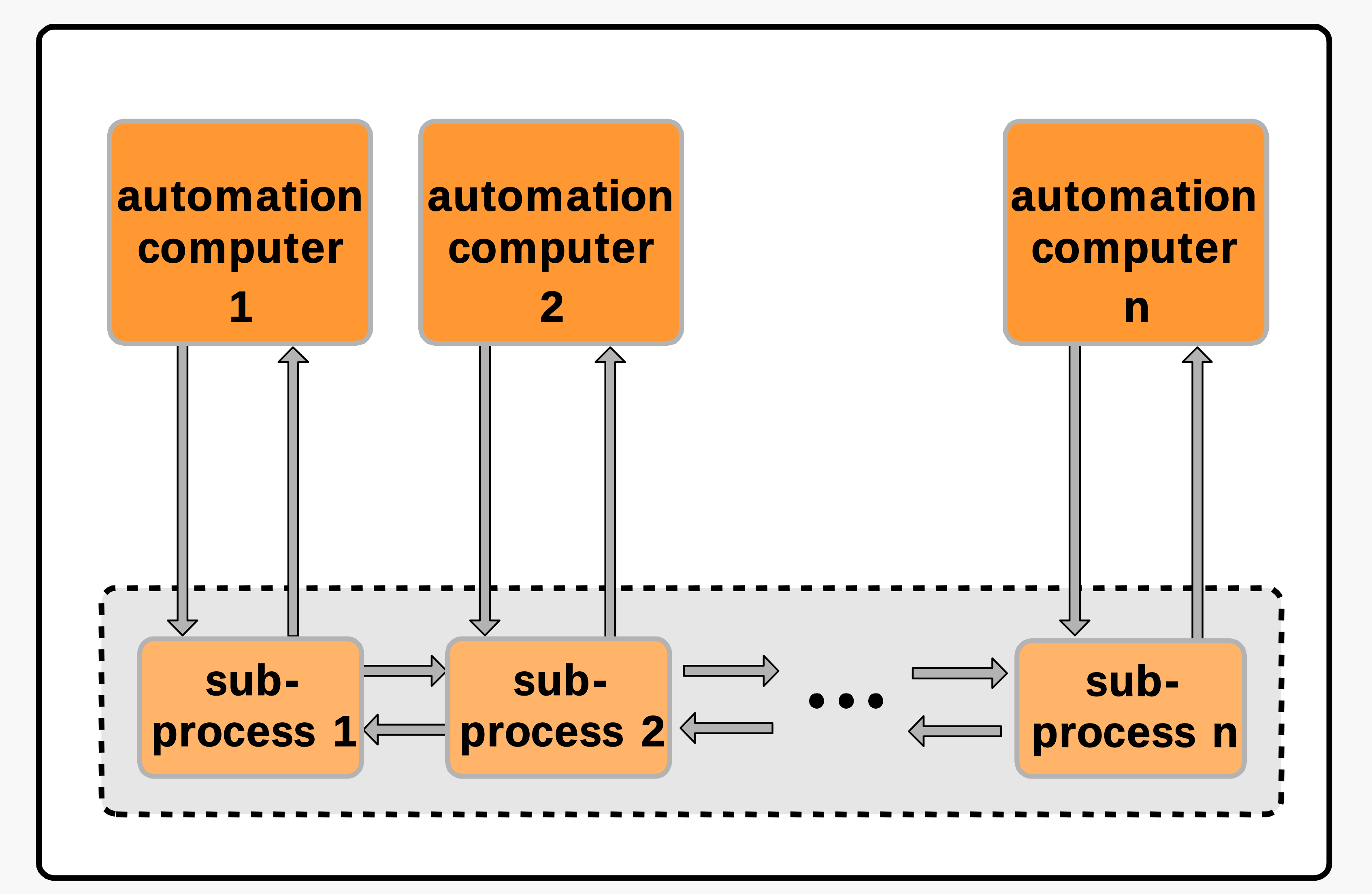


CM: connection module for sensors and actuators

Functionally centralized automation structure


central automation computer
sub-process 1
sub-process 2
...
sub-process n
technical process in a technical system

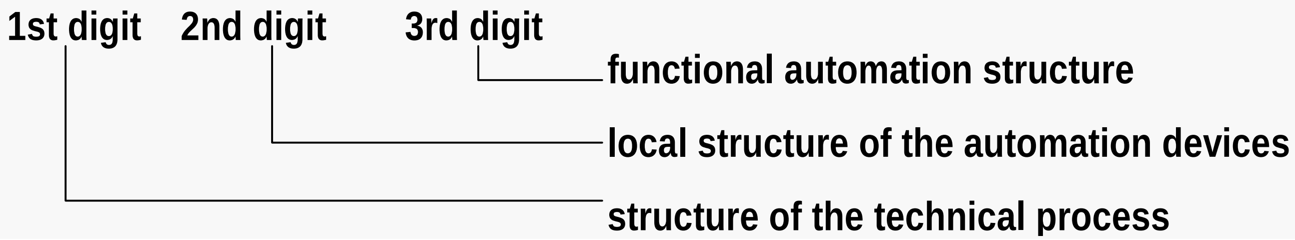
Functionally decentralized automation structure



Different combinations of automation structures

		technical process seen as an entity (centralized process structure)		technical process segmented into sub-processes (decentralized process structure)	
		locally centralized deployment of automation devices	locally decentralized deployment of automation devices	locally centralized deployment of automation devices	locally decentralized deployment of automation devices
functional structure	functionally centralized automation structure	CCC	CDC	DCC	DDC
	functionally decentralized automation structure	CCD	CDD	DCD	DDD

notation of the different structures: C = centralized / D = decentralized



1st digit 2nd digit 3rd digit

functional automation structure

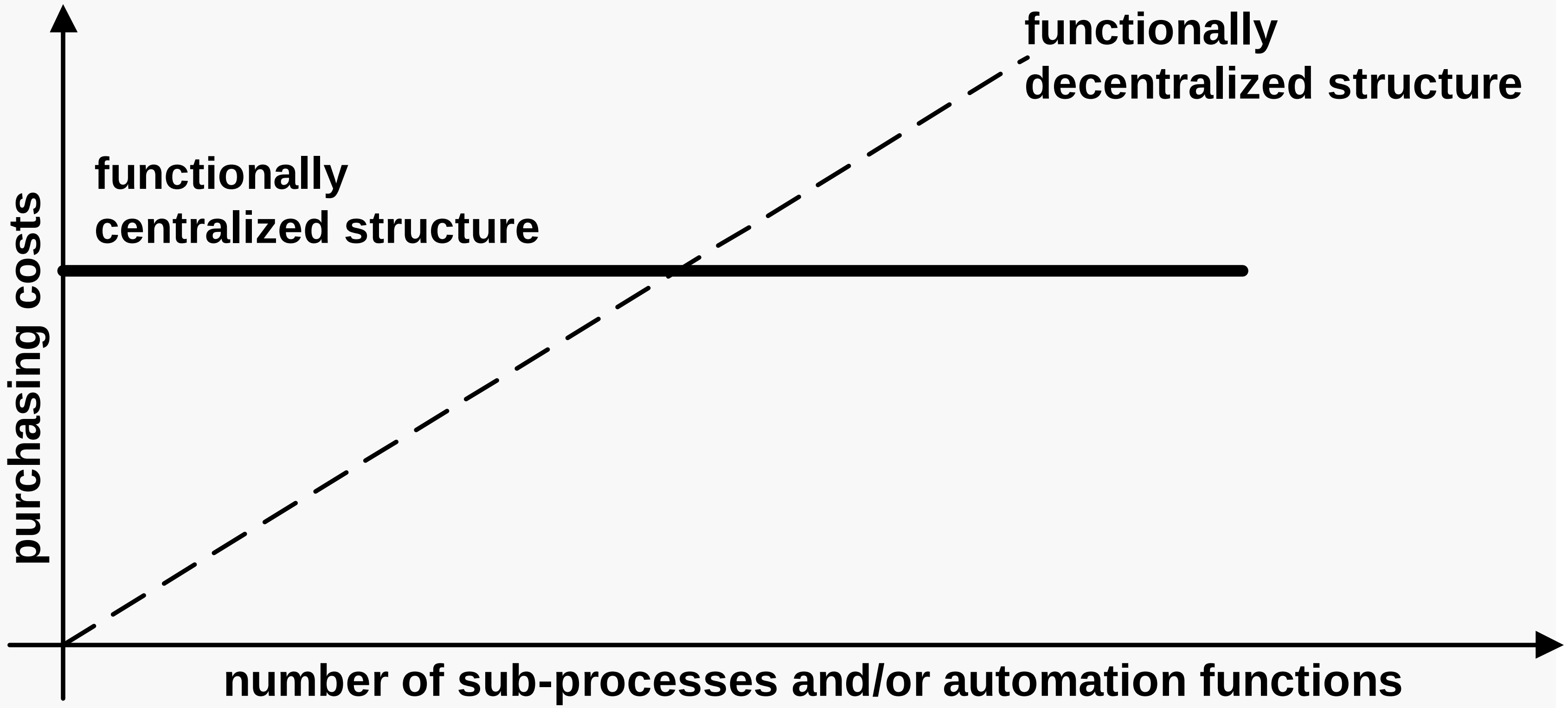
local structure of the automation devices

structure of the technical process

Criteria for a comparison of automation structure features

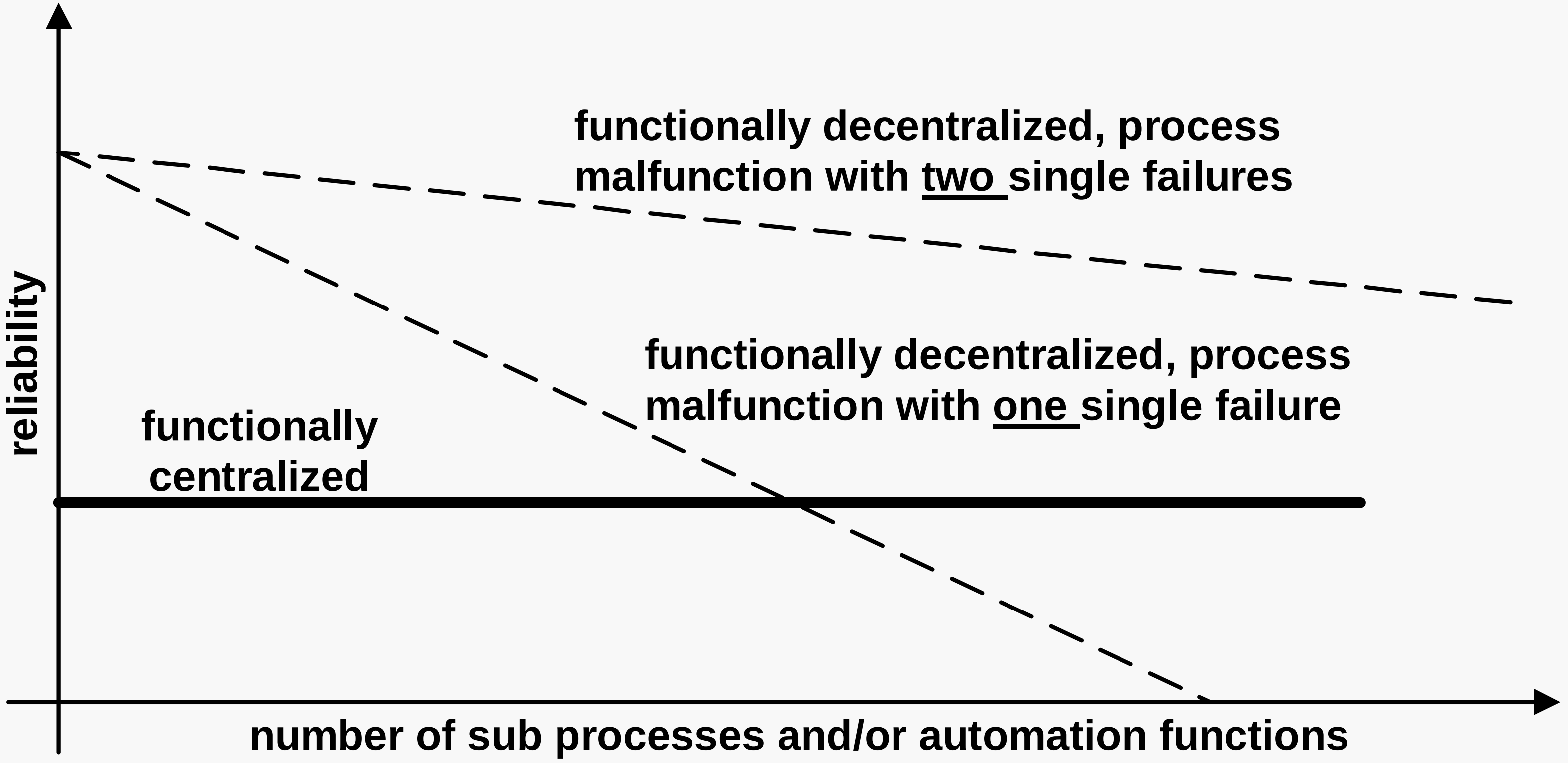
- Costs for devices, cabling, software, maintenance and service
- Availability of parts in case of hardware failure or software faults
- Flexibility in case of modifications
- Coordination of sub processes and optimization of the overall process
- Operability/usability

Comparison of purchasing costs



central structure with certain reserve causes no additional costs when upgrading

Comparison of reliability during operation of technical processes



Generally weak coupling

- No complete failure if two or more automation units fail
- Operational reliability is higher in the case of a functionally decentralized structure than the deployment of a central process computer

Decentralized structure

+	flexibility in case of modifications
+	coordination of sub-processes
+	optimization of the overall process
-	additional effort for the communication between the individual automation units
0	operability and user-friendliness
+	localization of malfunctions
+	higher transparency

Evaluation of automation structures regarding the criteria

C = centralized structure
D = decentralized structure

CCC	typical for the automation of small devices
CDC	lower cabling costs as in CCC
DCC	unfavorable regarding availability, maintenance, cabling costs
DDC	unfavorable regarding availability and flexibility
CCD	favorable regarding maintenance and flexibility, unfavorable regarding cabling
CDD	favorable regarding flexibility, availability, cabling and transparency
DCD	favorable regarding availability, maintenance, unfavorable regarding cabling costs
DDD	favorable regarding flexibility, availability, cabling and transparency

product automation

plant automation

automotive electronics

functional structure
local structure of the automation devices
structure of the technical process

ð As decentralized as possible, as centralized as necessary

§ 2 Automation Device Systems and Structures

2.1 Automation computers

2.2 Centralized and decentralized structures

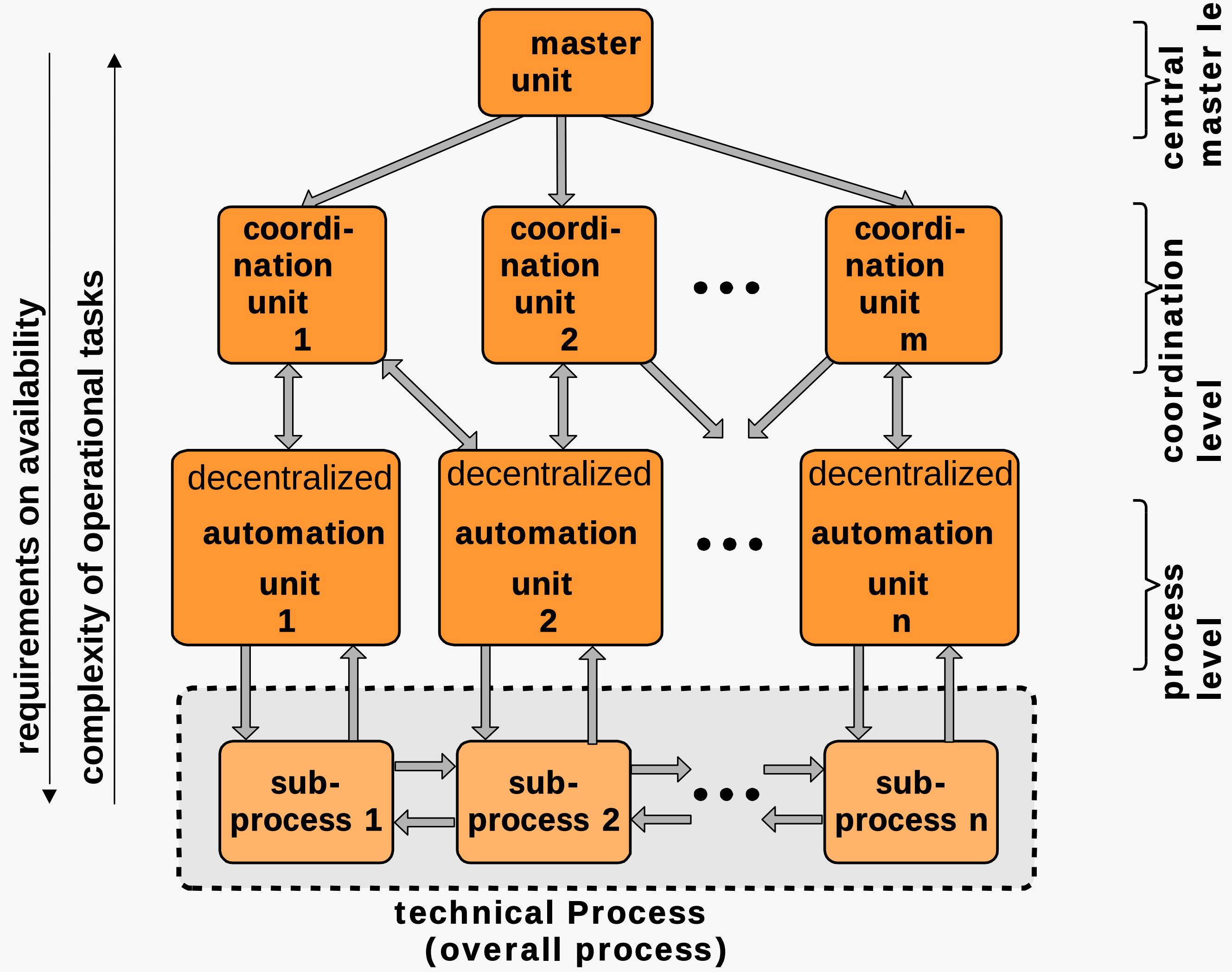
2.3 Automation hierarchies

2.4 Distributed automation systems

2.5 Automation structures with redundancy

Combination of centralized and decentralized structures

Ù Introducing a hierarchy of automation units


master unit
coordi-nation unit 1
coordi-nation unit 2
coordi-nation unit m
decentralized automation unit 1
decentralized automation unit 2
decentralized automation unit n
sub-process 1
sub-process 2
sub-process n
technical Process (overall process)
requirements on availability
complexity of operational tasks
central master level
coordination level
process level

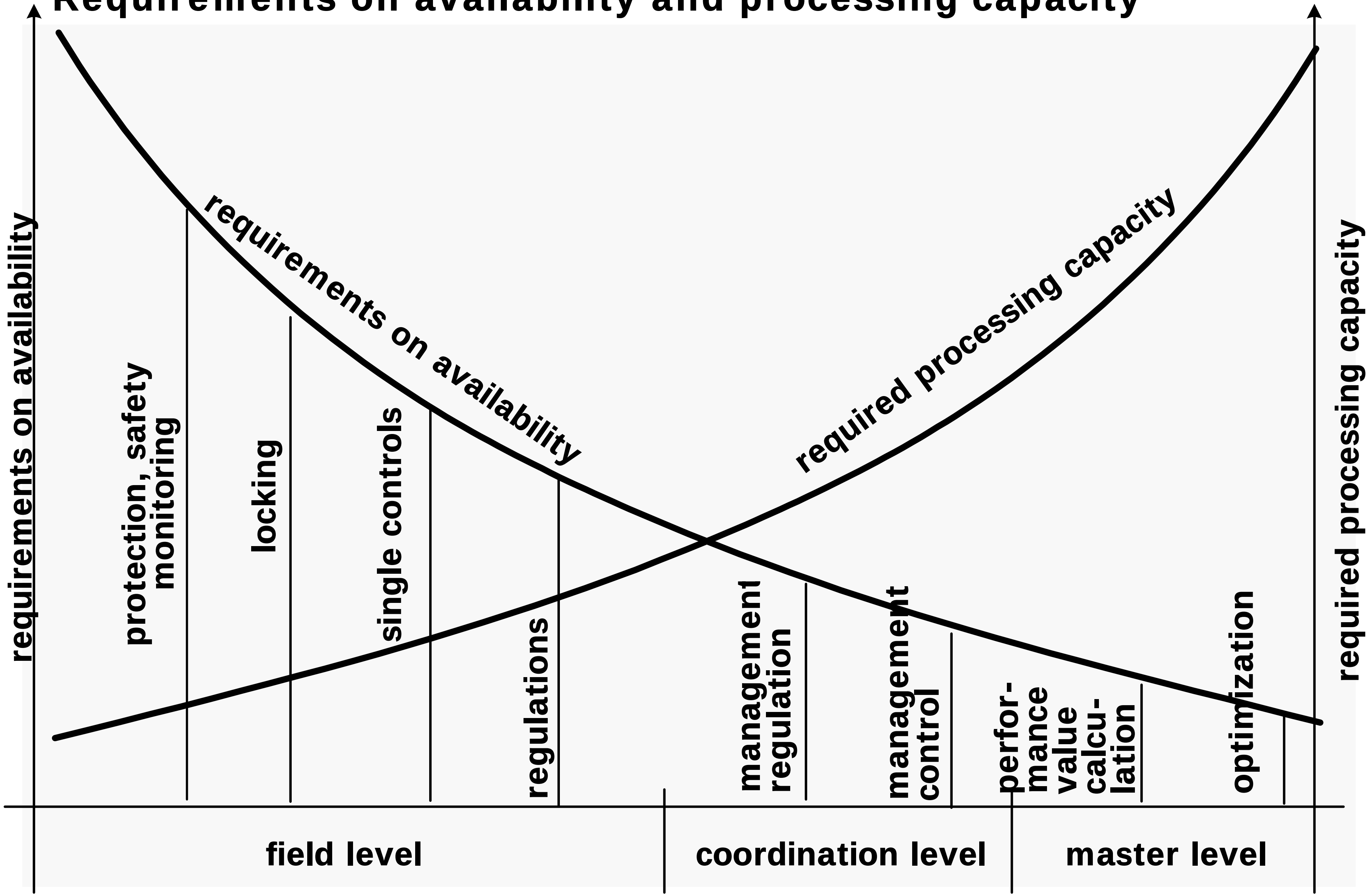
Allocation of automation functions to the process management levels

- decentralized automation units perform tasks of the field level, high requirements on availability

- coordination units perform the automation functions of the process level, as well as the coordination of sub-processes, optimization, process monitoring and safety functions

- master units perform the tasks of the operational level

Requirements on availability and processing capacity


requirements on availability
protection, safety monitoring
locking
single controls
regulations
management regulation
management control
perfor-mance value calcu-lation
optimization
required processing capacity
requirements on availability
required processing capacity
field level
coordination level
master level

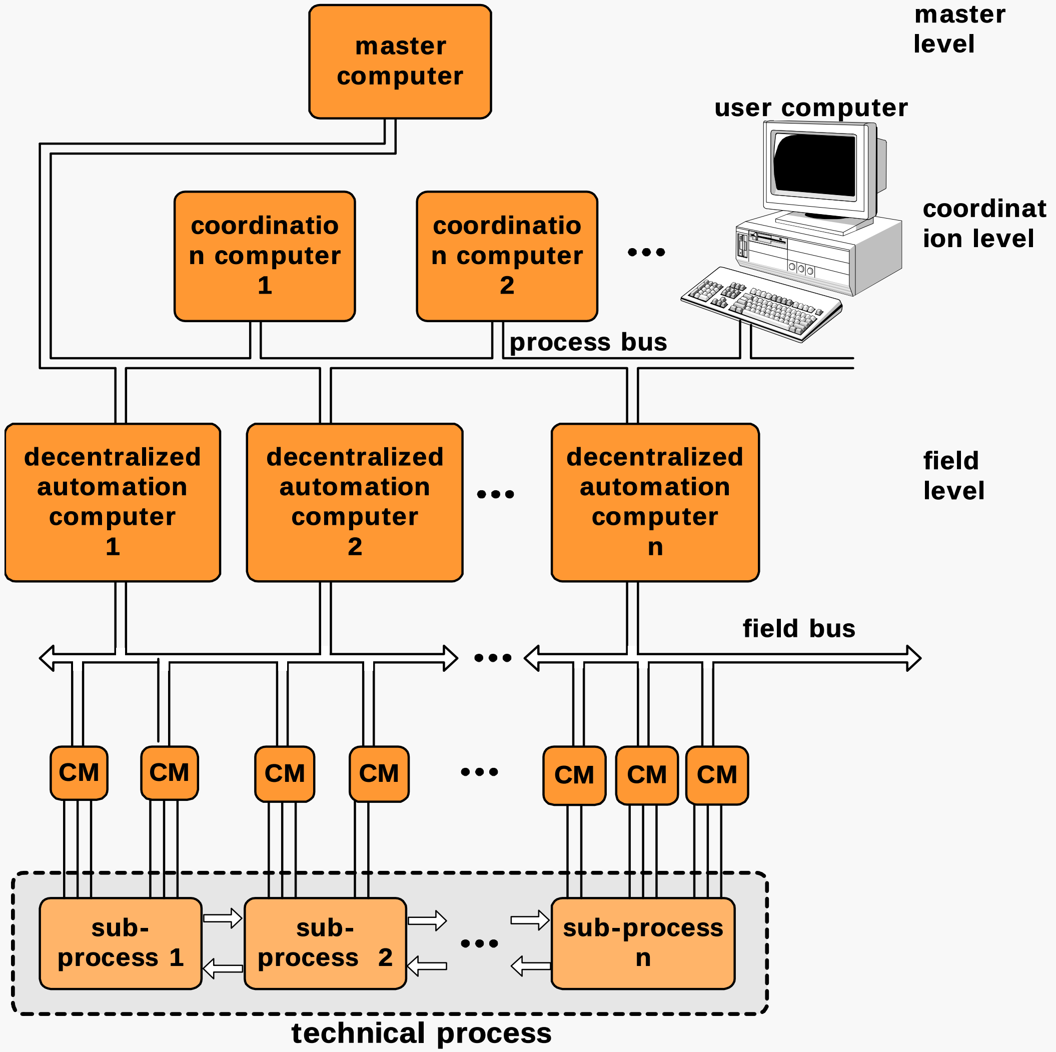
Prerequisites for the realization of an automation hierarchy

- segmentation of the technical process into sub-processes
- deployment of intelligent automation units
- communication system between automation units

Depending on the size of the company and the extent of the technical process, sub-levels can be added or levels can be joined.

Example

Realization of an automation hierarchy with a bus-oriented distributed process computer system



§ 2 Automation Device Systems and Structures

2.1 Automation computers

2.2 Centralized and decentralized structures

2.3 Automation hierarchies

2.4 Distributed automation systems

2.5 Automation structures with redundancy

Objectives when using distributed automation systems

- High reliability through fault tolerance
  - failure of a decentralized computer does not lead to an overall failure
  - isolation of the fault by means of reconfiguration
- Increase of availability through rapid maintenance and service
  - mutual control with fault diagnostics
- Mutual support during peak load times
  - automatic adaptation of the task distribution
  - reduction of the standby capacity of the individual units
- Simple upgradeability

Realization when using distributed automation systems

- Connection of decentralized automation units with a superordinated computer via a communication system

no hierarchy

Difference to the automation hierarchy

- In automation hierarchy, units only communicate with the level directly above it
- Only the process-related information tasks are perceived as decentralized

Selection of a communication system (1)

- Low cabling costs

essential costs: more cable cause more interferences in the wires

- Standardized interfaces regarding
  - plugs, cables (mechanical)
  - voltage level (electrical)
  - transmission protocol (logical)

- Flexibility in case of modifications

- Low requirements on the communication partner
  - demand on memory size
  - demand on computation power

- High availability and reliability

Selection of a communication system (2)

- Error free transfer of information
  - utilization of test bits
  - acknowledgment of correct reception

- Achievement of high data transmission rates

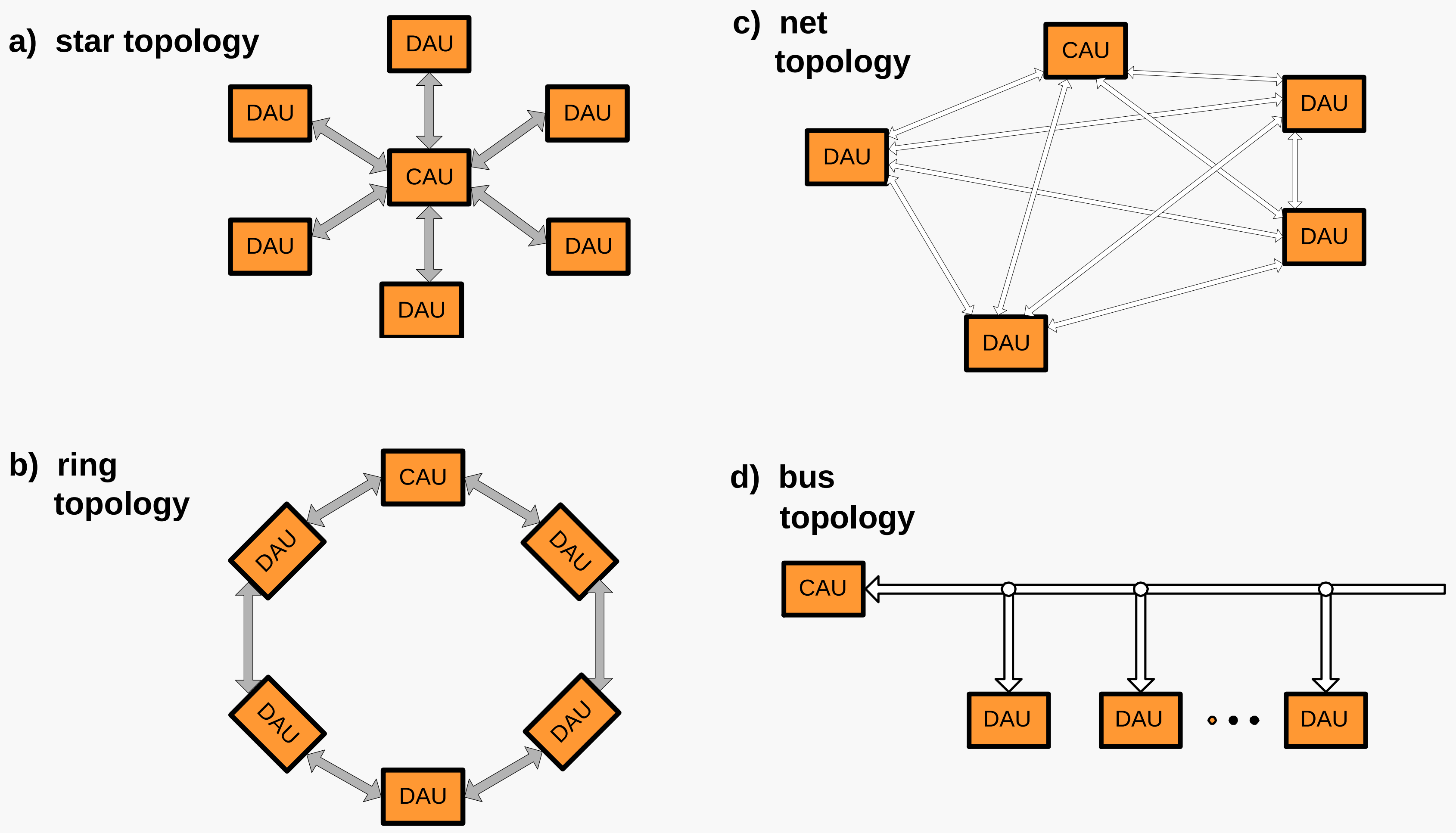
- Short reaction times on transmission requests

- Coupling of various communication partners

Problem:
Definition of priorities in the realization of the partially contradicting criteria

e.g.: high availability and reliability through redundant bus systems can cause high cabling costs

Basic topologies of communication



a) star topology

b) ring topology

c) net topology

d) bus topology

CAU = centralized automation unit

DAU = decentralized automation unit

Basic topologies of communication

star topology

failure of the central unit causes failure of the communication system

ring topology

each unit can only transmit messages to its direct neighbors

net topology

parallel information transmission, short reaction time, many interfaces, high cabling costs

bus topology

only one participant at a time is able to send, simultaneous information reception from all participants

Parallel bus

- addresses, data and control signals are transmitted parallel
- bundles of wires

distance: up to 20 m

Serial bus

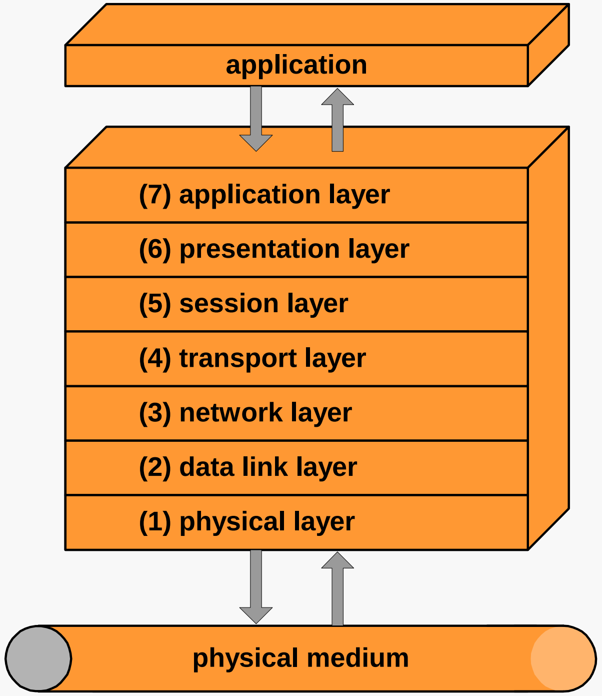
- bits of a message are transmitted one after another
- transmission time is longer than that of parallel bus
- lower cabling costs
- increase of reliability
- flexibility regarding the transmission protocol

distance : 20 m up to 15 km

Types of communication systems

- Open communication system

  OSI = Open-System-Interconnection



ISO IS 7498

- Manufacturer-specific communication system (proprietary systems)

  CSI = Closed-System-Interconnection

Tasks of ISO/OSI- layers

layer 7:	**Application layer**	- basic services - standard applications - application-specific
layer 6:	**Presentation layer**	- language adjustments (e.g., between ASCII & EBCDIC) - data encoding - data decoding
layer 5:	**Session layer**	- establish - control - stop communication
layer 4:	**Transport layer**	- route parallelism - packet retransmission - packet sorting
layer 3:	**Network layer**	- net protocols - data addressing - data switching - routing
layer 2:	**Data link layer**	- error detection/ handling - access mode - synchronization
layer 1:	**Physical layer**	- transmission medium - type of coding - interface - topology

§ 2 Automation Device Systems and Structures

2.1 Automation computers

2.2 Centralized and decentralized structures

2.3 Automation hierarchies

2.4 Distributed automation systems

2.5 Automation structures with redundancy

Types of redundancy

Always: operating personnel monitoring parallel to process computer!

- Hardware redundancy
  - redundant hardware
- Software redundancy
  - redundant software
- Measured value redundancy
  - redundant measured value
  - dependent measured value
- Time redundancy
  - multiple inquiry of the same measured value in certain intervals

e.g.: velocity, acceleration

Hardware and software redundancy implies a bigger effort

– higher availability

– safety-relevant systems

Objectives when using fault-tolerant structures

Design the systems in such a way that they are able to function as a whole even if faults occur in individual components.

Levels of fault-tolerance

- complete fault-tolerance — **fail operational**
- reduced operational capacity — **fail soft, graceful degradation**
- transition to a safe state — **fail-safe**

The principle of fault-tolerance

Construct a system with redundant modules (hardware and software) in order to maintain a functioning system in case errors occur.

Types of redundancy

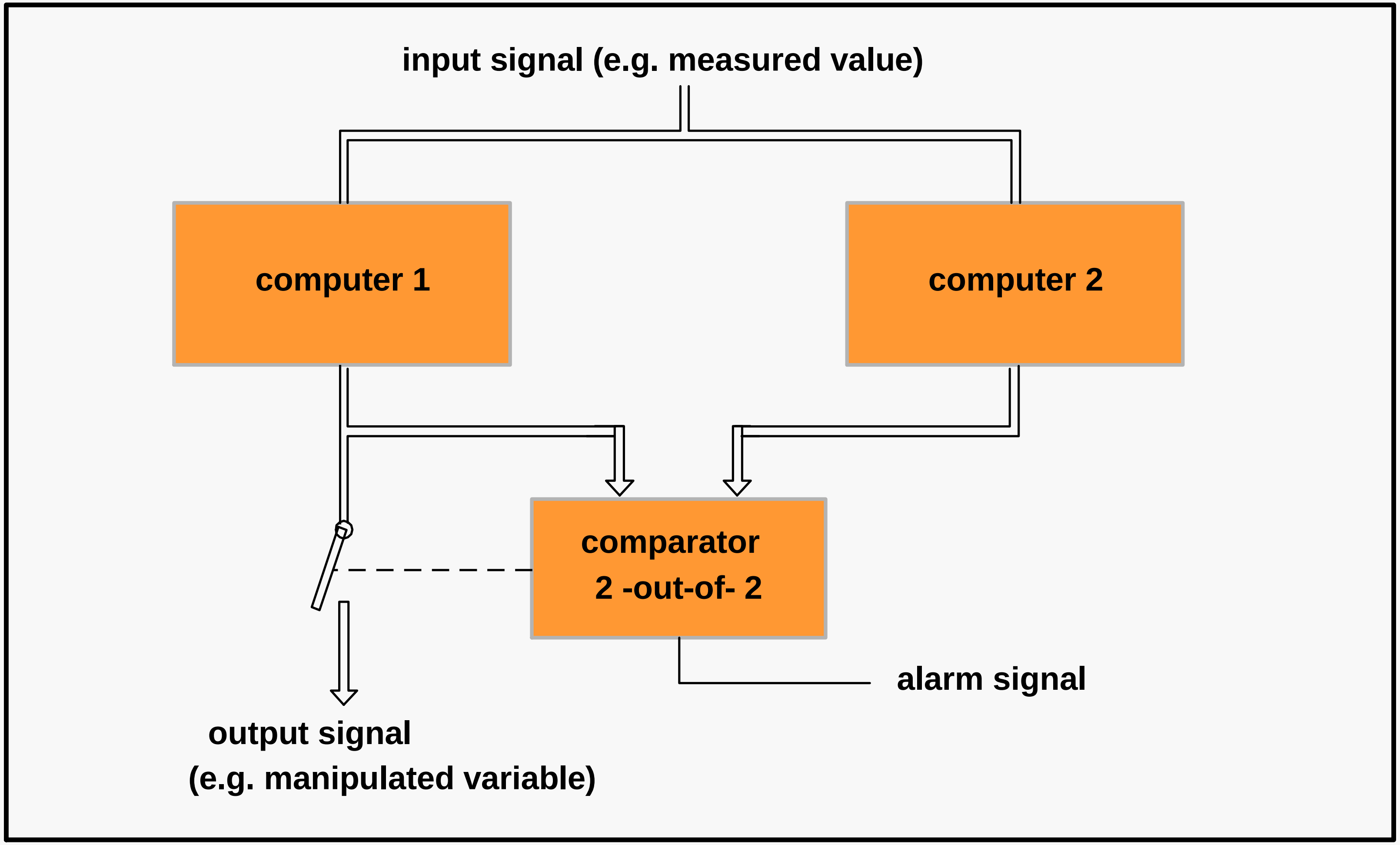
– Static redundancy
  - all redundant modules are permanently in operation

– Dynamic redundancy
  - redundant modules are only used after a failure occurs
  - blind redundancy
    redundant modules do not act in fault-free cases
  - function-participating redundancy
    redundant modules run stand-by-functions in fault-free cases

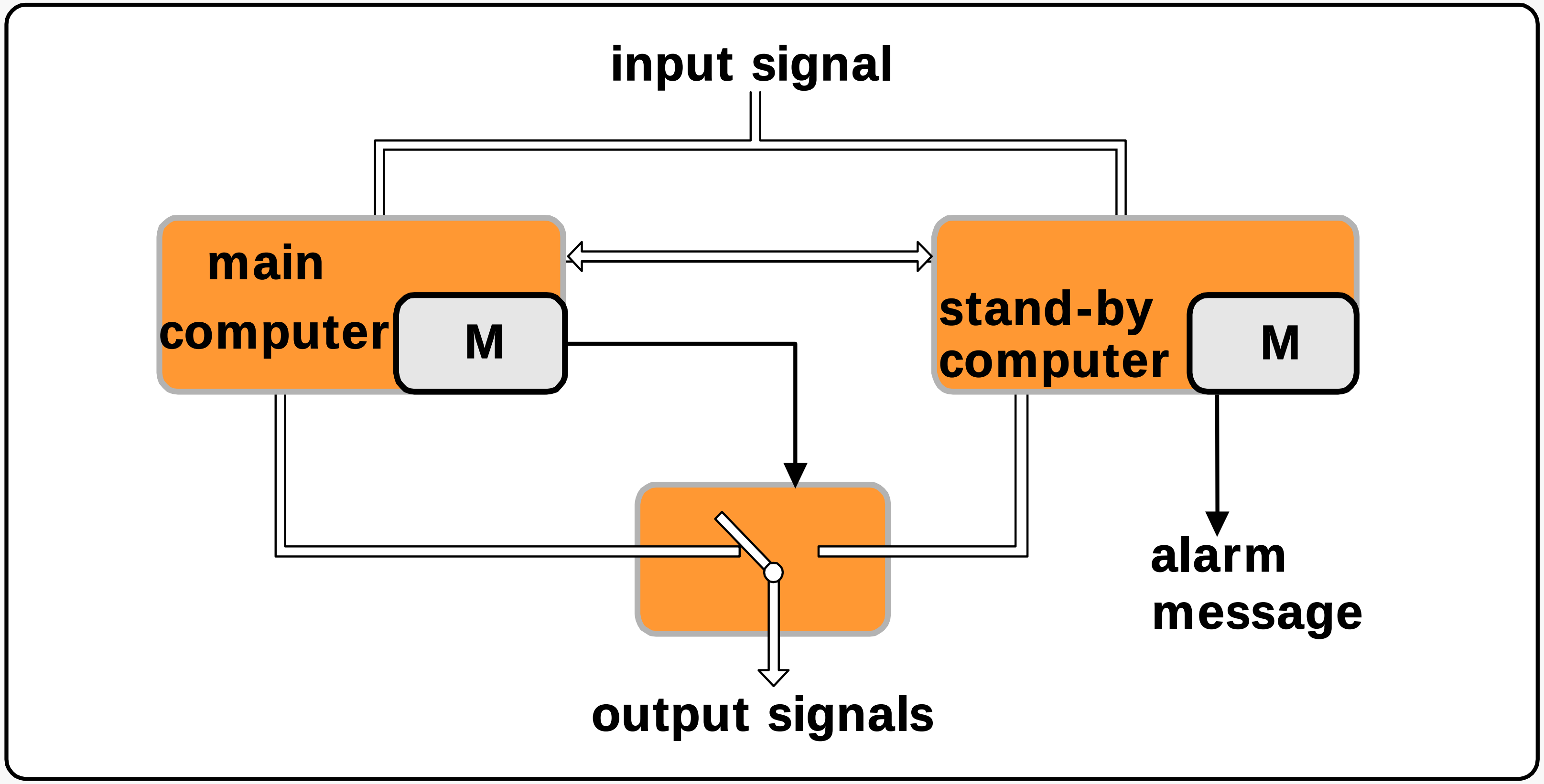
Hardware redundancy

- Goal:
  Detection of hardware failures
- Operation principle:
  m-of-n-redundancy
    - majority ruling
    - no faults, until multiple defects occur
- Realization of redundancy
    - double computer structures
    - triple computer structures

Double computer structures with static redundancy

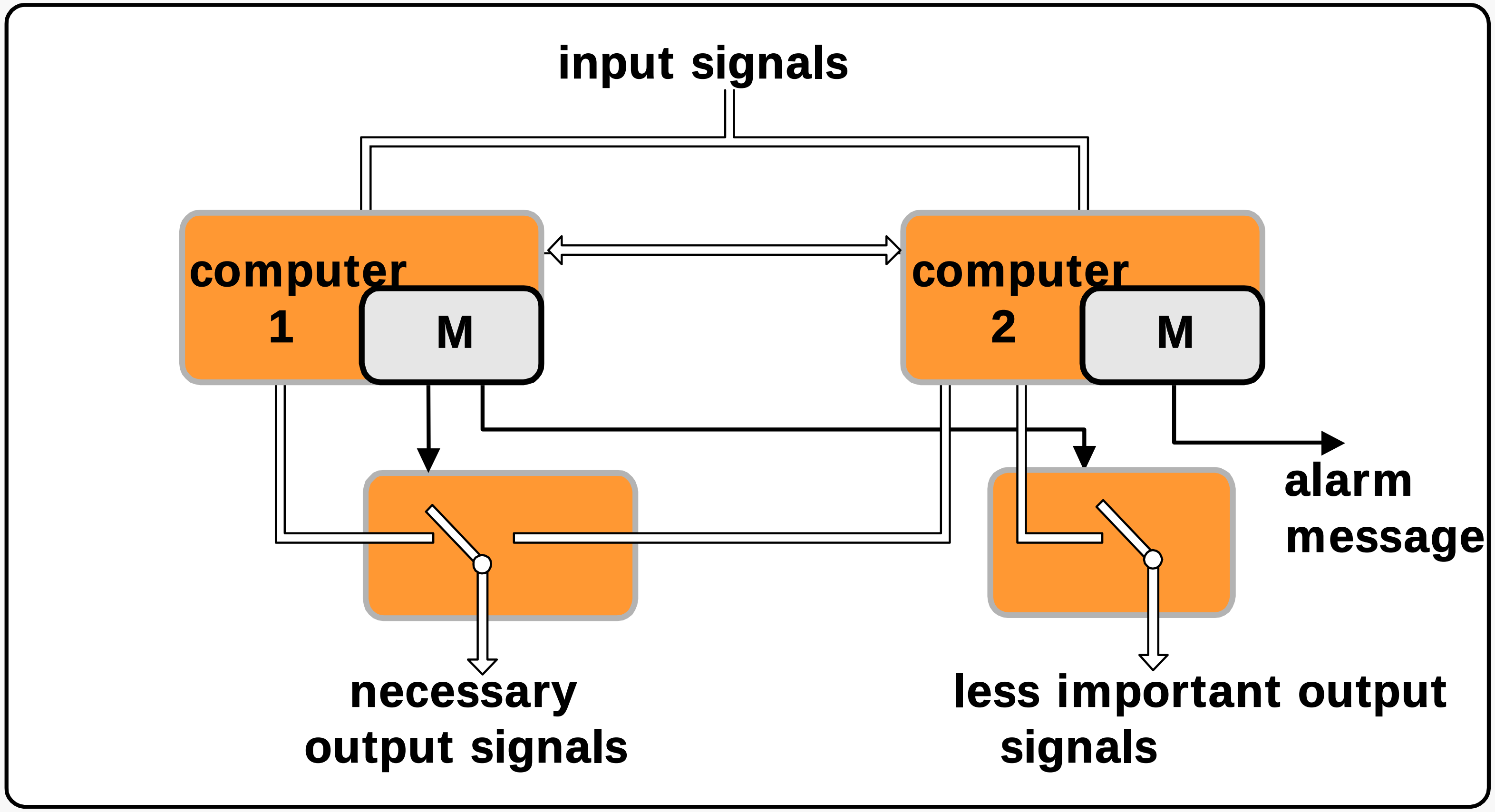


Double computer structures with dynamic blind redundancy



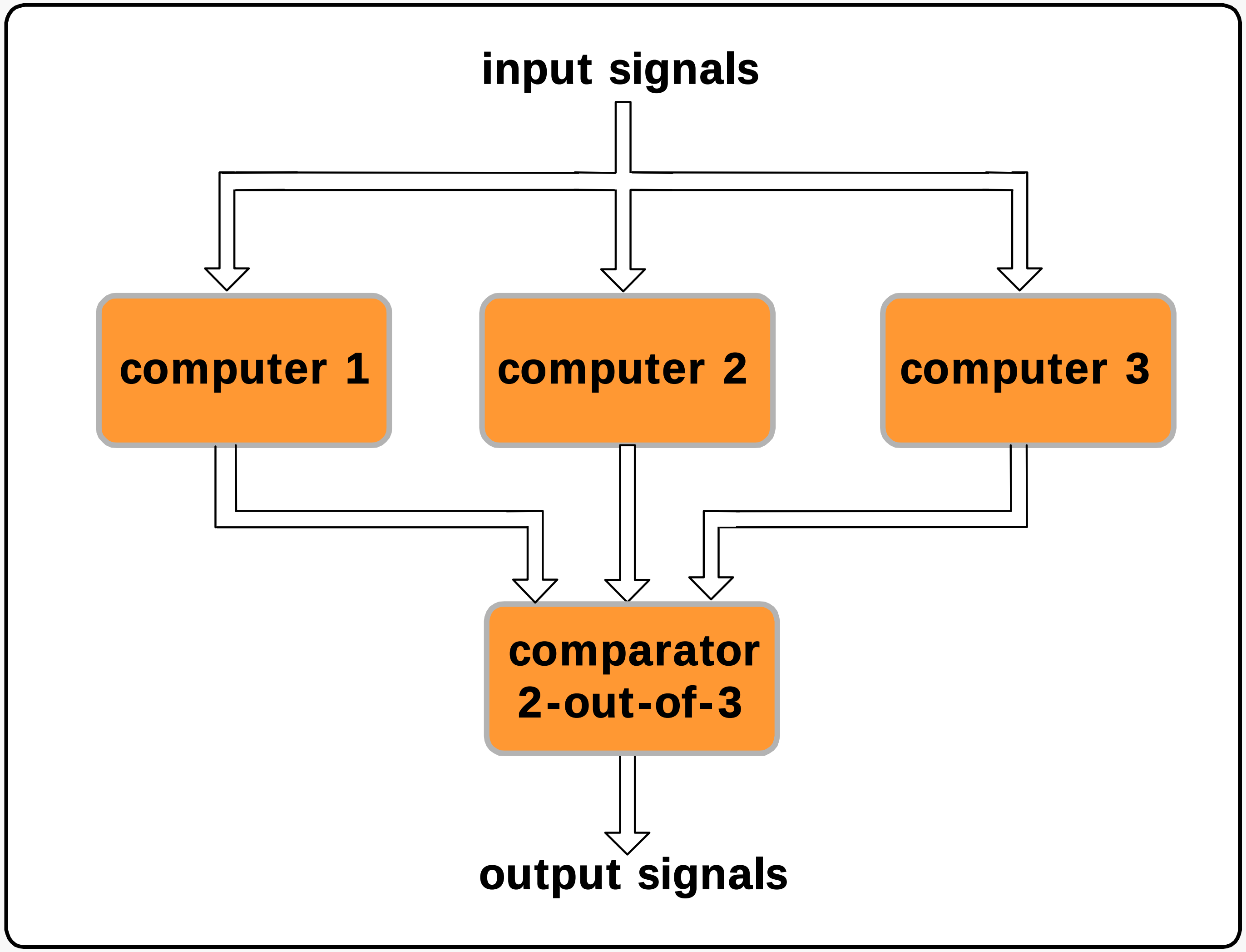
M = Monitoring Program

Double computer structures with dynamic function-participating redundancy



M = Monitoring Program

Triple computer structures with static redundancy



Software redundancy

- Objective:

  detection of errors in software

- Starting point:

  software has errors

Redundancy measures for software
existence of the same software makes no sense, failure of software is not the problem

- heterogeneous structure of program components
- the same input data must lead to the same results

Diversity software

Diversity = Heterogeneity of software with identical functionality

- independent development teams solve the same problem
- intentional development of different strategies, algorithms and software structures

Application and execution of diverse software components

- Redundant software alternatives are executed one after another and are compared with the help of a voter (not for real-time systems with high requirements on timeliness)
- simultaneous execution of redundant software components on redundant multi-computer systems
- cyclic alternation of diverse components

Comparison difficult

- Two algorithms with different processing times
- Both results can be correct even though their values might be different

Question referring to Chapter 2.4

The individual modules of a PLC are connected via a manufacturer specific bus. For the communication between field devices a field bus is often used.

Explain at this example the difference between an „open“ and a „proprietary“ communication system.

Answer

The PLC bus system is a proprietary communication system. This means, it is a manufacturer-specific system where only devices made by the same manufacturer can communicate with each other.

A field-bus system is an open communication system. Devices of different manufacturers can be connected with this system

Question referring to Chapter 2.4

There are some different topologies for a communication system. Which of the following statements do you agree?

Answer

ü the bus topology causes the lowest cable expense

f ¨ the bus topology is faster than the net topology

ü a net topology is able to broadcast a larger amount of data in parallel than a bus topology

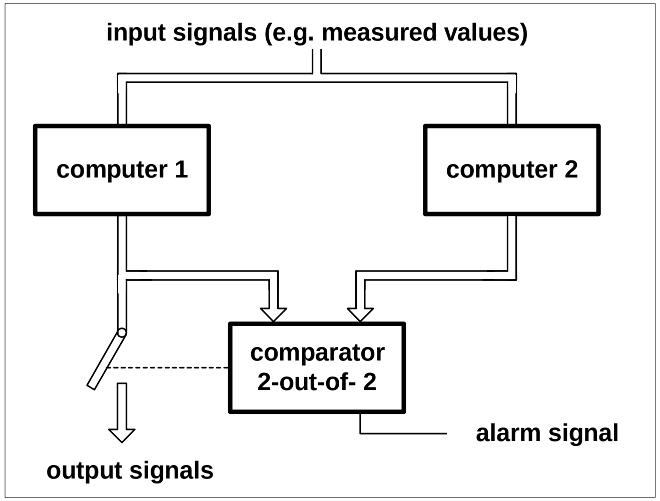
f ¨ a bus topology has a shorter reaction time than a net topology

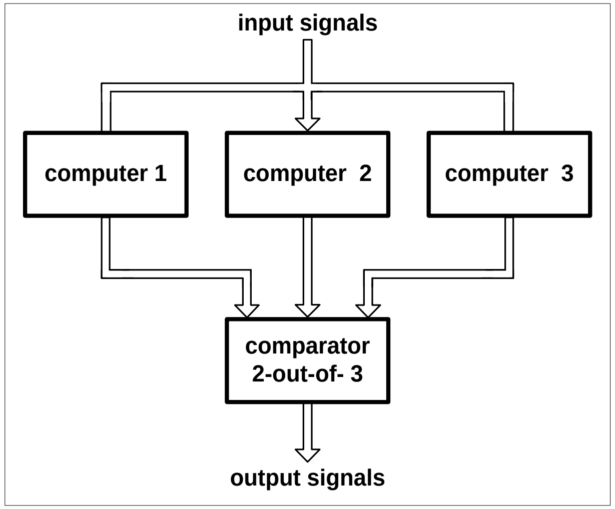
f ¨ it is easier to expand a net topology than a star topology

f ¨ a bus topology is only suitable for decentralized systems

Question referring to Chapter 2.5

In aircraft's important systems, variables are calculated more than once. Which kind of system would you use for this application: a double or a triple computer system with static redundancy ?

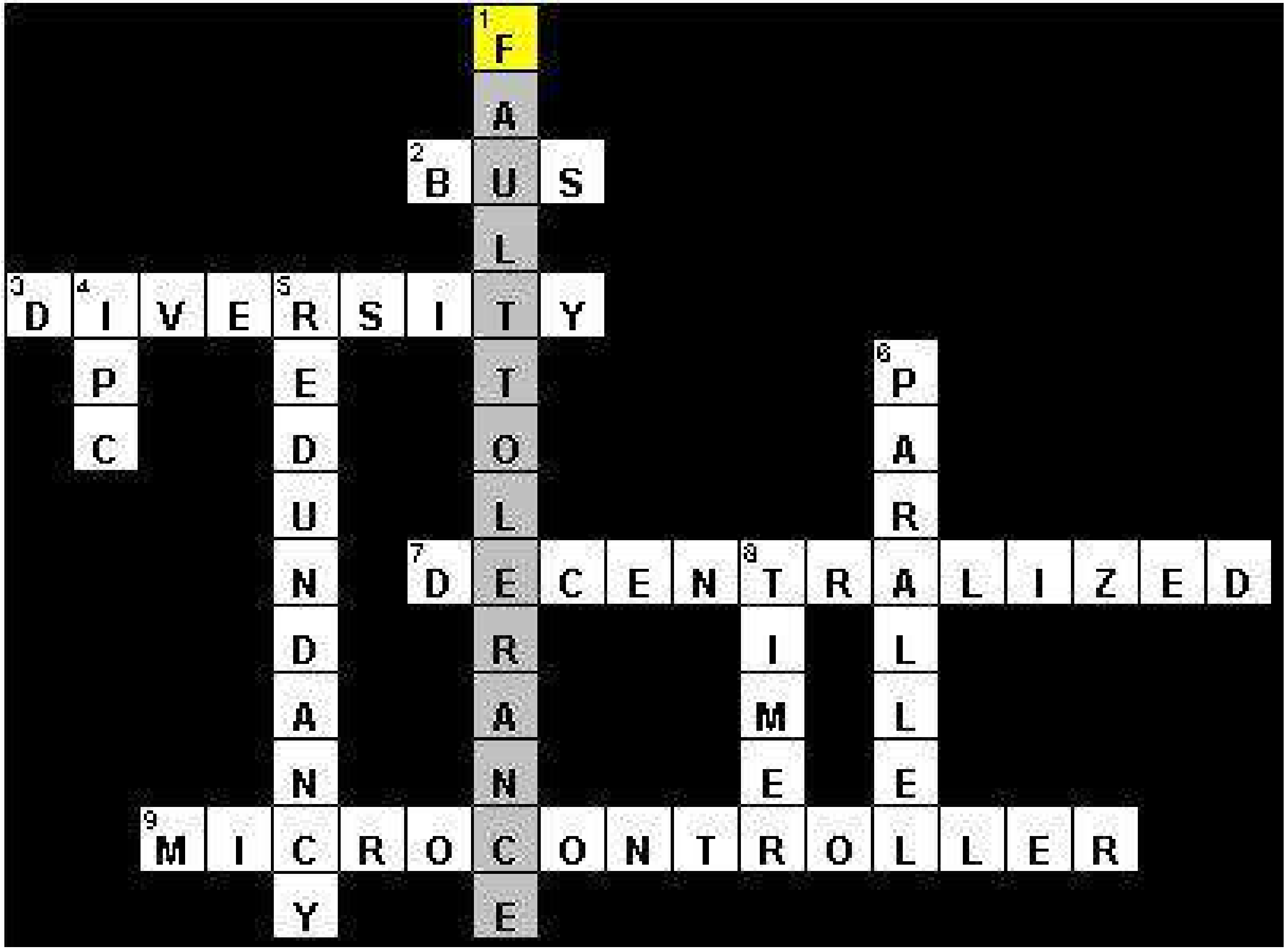




Answer

A double computer system with static redundancy is not fault-tolerant. In case of a failure the system is shut down.
Therefore, a triple computer system has to be used. Because of the 2-out-of-3 decision, this type of system is fault-tolerant.

Crosswords to Chapter 2



							1 F											
							A											
						2 B	U	S										
							L											
3 D	4 I	V	E	5 R	S	I	T	Y										
	P			E			T						6 P					
	C			D			O						A					
				U			L						R					
				N		7 D	E	C	E	N	8 T	R	A	L	I	Z	E	D
				D			R				I		L					
				A			A				M		L					
				N			N				E		E					
		9 M	I	C	R	O	C	O	N	T	R	O	L	L	E	R		
				Y			E											

Crosswords to Chapter 2

Across

2 Communication medium (3)

3 Heterogeneity of software with identical functionality (9)

7 Physically distributed (13)

9 One chip computer (15)

Down

1 Preservation of the functionality despite occurrence of errors. (5,9)

4 Abbreviation for computers specially designed for usage in industrial fields. (3)

5 Duplication of hardware or software elements with the same functionality. (10)

6 Simultaneous transmission of data on several lines. (8)

8 Time impulse generator (5)